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September 2006

Technical Work Plan For: Calculation of Waste Package and Drip Shield Response to Vibratory Ground Motion and Revision of the Seismic Consequence Abstraction

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Bechtel SAIC Company, LLC

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September 2006

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CHANGE HISTORY

Revision Number	ICN Number	Date of Change	Description of Change
00	00	4/1/2005	This TWP supersedes TWP-MGR-GS-000003 REV 00 ICN 01. Initial issue of analysis of waste package and drip shield response to vibratory motion activities under work package ADEM21. Seismic Consequence Abstraction, REV 01, will also be revised under this TWP. Other postclosure seismic modeling activities also found in work package ADEM21 are described in TWP-MGR-GS-000001 REV 03, ICN 02.
01	00	05/30/2006	This TWP supersedes and is a complete revision of TWP-MGR-GS-000004 REV 00. Change bars are not being used because of the extensive revisions for this TWP. Revised calculations of waste package, drip shield, and cladding response to vibratory ground motion and fault displacement under work package ADEM23. These new calculations will be based on the TAD canister and overpack, rather than on the 21-PWR waste package. The new calculations for structural response and rockfall response and the new seismic damage abstractions will be documented and validated in a revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) under this TWP.
01	01	09/25/2006	This ICN (i) clarifies the approach for documenting the structural response calculations, (ii) provides criteria for evaluating the importance of waste package-drip shield impacts, (iii) clarifies the nature of the analog studies for postdevelopment model validation, and (iv) incorporates typographic corrections in response to DOE comments on TWP-MGR-GS-000004 REV 01.

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ACRONYMS

AIN	Additional Information Need
BSC	Bechtel SAIC Company LLC
BWR	boiling water reactor
DHLW	defense high-level waste
EBS	engineered barrier system
ICN	Interim Change Notice
IVRT	Independent Validation Review Team
LLNL	Lawrence Livermore National Laboratory
NRC	U.S. Nuclear Regulatory Commission
PGV	peak ground velocity
PWR	pressurized water reactor
QARD	Quality Assurance Requirements and Description
TAD	transportable, ageable, and disposable
TWP	technical work plan
TSPA	total system performance assessment
YMRP	Yucca Mountain Review Plan

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1. WORK SCOPE

1.1 OBJECTIVES

The overall objective of the work scope covered by this technical work plan (TWP) is to develop new damage abstractions for the seismic scenario class in total system performance assessment (TSPA). The new abstractions will be based on a new set of waste package and drip shield damage calculations in response to vibratory ground motion and fault displacement. The new damage calculations, which are collectively referred to as damage models in this TWP, are required to represent recent changes in waste form packaging and in the regulatory time frame. The new damage models also respond to comments from the Independent Validation Review Team (IVRT) postvalidation review of the draft TSPA model regarding performance of the drip shield and to an Additional Information Need (AIN) from the U.S. Nuclear Regulatory Commission (NRC). The specific motivations for the new damage models are as follows:

- Pressurized water reactor (PWR) and boiling waste reactor (BWR) waste forms will be emplaced in a standardized transportable, ageable, and disposable (TAD) canister system (BSC 2006 [DIRS 176513]) at the reactor sites, and each TAD canister will be inserted into an overpack prior to emplacement at Yucca Mountain. The TAD canister and overpack is significantly heavier and longer than the 21-PWR waste package, which is the basis for the previous seismic damage calculations. In addition, the shield plug in the TAD canister shifts the center of gravity of the canister and overpack relative to the 21-PWR waste package. The increased weight, increased length, and the shift in center of gravity for the TAD canister and overpack versus a 21-PWR waste package are being incorporated into the revised seismic damage models through this TWP. The TAD canister and overpack are referred to as the TAD-bearing waste package throughout this document.

- The seismic scenario class must consider degraded states of the Engineered Barrier System (EBS). The seismic scenario class previously represented degradation of EBS components by a 2-mm reduction in the thickness of the outer barrier of the waste package and by a 2-mm reduction in the thickness of drip shield structural elements. This approach is not comprehensive enough for very long time scales for two reasons. First, general corrosion may reduce the thickness of structural elements by much more than 2 mm over very long time scales. Second, failure of a component can change the state of the EBS for subsequent seismic events. Two examples will illustrate the potential changes when a component fails.

- An intact drip shield protects the waste packages from rockfall and allows the waste packages to move freely beneath the drip shield during a seismic event. However, failure of the drip shield plates may result in a waste package surrounded by rubble that restrains the motion of the waste package. The potential for failure of the drip shield plates is represented as fragility curves that will be developed under this TWP. These fragility curves also respond to a concern raised by the IVRT, who questioned the lack of failures in drip shield performance (Booth 2006 [DIRS 176638]). The IVRT concern is met (in part) by the drip shield fragility curves, which provide a probabilistic representation of drip shield failure as a function of general corrosion, the accumulated weight of rubble on top of the drip shield, and the intensity of a seismic event.

As a second example of a change of state, failure of the waste package outer barrier may initiate corrosion of the inner vessel and waste form, potentially increasing the mass of the degraded internals and decreasing their capacity to support a structural load. The potential for degradation of the inner vessel and waste form is being incorporated into the revised seismic damage models through this TWP.

- The seismic scenario class must explicitly consider multiple events for very long time scales. The seismic scenario class previously calculated mean dose by forcing a single seismic event to occur in each realization and using a probabilistically derived formula to define the mean dose. This approach is most applicable when multiple seismic events occur very infrequent over the time scale of interest. However, multiple seismic events become the norm over very long time scales, so multiple events are being incorporated into the revised seismic damage abstractions for TSPA through this TWP.

The work performed under this TWP will be documented in a revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). This revision will document the damage models that provide the input data for the seismic damage abstractions and will document the development of the damage abstractions for the seismic scenario class in TSPA. This revision will document the validation of the seismic damage models and seismic damage abstractions. This revision will also provide better traceability for Data Tracking Numbers (DTNs): MO0303SPARBPDS.000 and MO0303SPARESST.000, as required to resolve CR 5110.

Documentation of the damage models and damage abstractions in a single model report is consistent with the Quality Assurance (QA) procedures for the Yucca Mountain Project. Preparation of a report in accordance LP-SIII.10Q-BSC, *Models*, is a reasonable approach because it provides a single, comprehensive source of information for the seismic damage abstractions and the supporting damage models for the seismic scenario class for TSPA.

The damage models for this TWP will be performed by the structural engineering group at Lawrence Livermore National Laboratory (LLNL) and by the Itasca Consulting Group in accordance with LP-SIII.10Q-BSC. The development of the seismic damage abstractions will be performed by the staff of Bechtel SAIC Company, LLC (BSC).

Previous calculations for the seismic scenario class were documented in *Mechanical Assessment of the Waste Package Subjected to Vibratory Ground Motion* (BSC 2004 [DIRS 173172]) and *Mechanical Assessment of the Drip Shield Subject to Vibratory Motion and Static and Dynamic Rock Loading* (BSC 2004 [DIRS 169753]). These calculation reports were prepared in accordance with AP-3.12Q, *Design Calculations and Analyses*. Since these reports were completed, AP-3.12Q has been retired and replaced with EG-PRO-3DP-G04B-00037, *Calculations and Analyses.* EG-PRO-3DP-G04B-00037 has been written to support the design organization, and is not easily adapted for documentation of scientific calculations. In this situation, the seismic calculations for this TWP will be documented as appendices to the next revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) that will be prepared under LP-SIII.10Q-BSC, *Models*.

1.2 MAJOR ACTIVITIES AND PRODUCTS

This TWP includes major activities necessary to provide new damage abstractions associated with postclosure vibratory ground motion and fault displacement for the TAD-bearing waste package. Since the design of the TAD canister and its overpack is not currently available, the Site-Specific Canister (BSC 2005 [DIRS 173447], Attachment 1) and the Naval Long waste package (BSC 2003 [DIRS 165158]; BSC 2003 [DIRS 165159]) will be used as surrogates for the TAD canister and overpack for all damage calculations under this TWP. The design of the Site-Specific Canister will be controlled during the technical activities for this TWP by submitting a future proposal to the Technical Management Review Board to freeze the current design of the SSC.

The damage models described in this TWP are conducted in five tasks. There is also a sixth and seventh task to develop the abstractions for TSPA based on the computational data from the first five tasks. The individual tasks are summarized here. Sections 2.2 and 2.3 provide detailed descriptions of the technical approach and scope for each task.

- Task 1: Kinematic Calculations. The first task consists of three-dimensional numerical calculations for the kinematics of waste package movement associated with (postclosure) vibratory ground motion. These kinematic calculations, in combination with three-dimensional finite-element calculations for the damage from individual impacts, determine the probability of rupture and the magnitude of damaged areas[1] in response to vibratory ground motion for multiple waste packages in an emplacement drift. The probability of rupture and the damaged areas will be used as the basis for new seismic damage abstractions for TSPA.

- Task 2: Waste Package Surrounded by Rubble. The second task consists of numerical calculations for the damaged areas on a single waste package surrounded by rubble in response to vibratory ground motion. These calculations represent the response of the EBS after the drift has collapsed and the drip shield plates have failed, so that the waste package is surrounded by rubble. These calculations determine probability of rupture and the magnitude of the damaged areas that will be used as the basis for new seismic damage abstractions for TSPA.

- Task 3: Drip Shield Failure Mechanisms. The failure mechanisms of the drip shield will be evaluated with numerical calculations to determine the seismic event that changes the EBS configuration. The change in EBS configuration causes the damage abstractions to switch from the kinematic representation to the representation for a waste package surrounded by rubble or another appropriate configuration in TSPA. These failure mechanisms will include consideration of rupture of the drip shield plates and the potential for collapse of the drip shield framework. These mechanisms will also consider the potential for drip shield failure from impacts between the lip of the waste

[1] Throughout this TWP, damaged area refers to a deformed region where the residual stress exceeds the (tensile) threshold for initiation of stress corrosion cracking. Rupture refers to complete mechanical failure, when a material exceeds its ultimate tensile strength.

package and the internal bulkheads of the drip shield. These failure mechanisms will be represented as a set of fragility curves that are functions of drip shield thickness, seismic intensity, and the static rockfall load on the drip shield.

- Task 4: Drip Shield Damaged Areas. The damaged areas on the drip shield will be abstracted for TSPA if FEP 2.1.03.10.0B, Advection Through Cracks in the drip shield, is screened in. The status of FEP 2.1.03.10.0B will depend on technical studies that will be performed under *Technical Work Plan for: Near-Field Environment: Engineered Barrier System: Radionuclide Transport Abstraction Model Report,* TWP-MGR-PA-000020 REV 02 (in process). The results of these technical studies will be summarized in revisions to the Disruptive Events FEP report (BSC 2004 [DIRS 171850]) and the EBS FEP report (BSC 2005 [DIRS 175014]). If needed, the damaged areas on the drip shield will be evaluated through numerical calculations in response to vibratory ground motion and in response to rockfall induced by vibratory ground motion. The resulting damaged areas will be used as the basis for new seismic damage abstractions for the drip shield for TSPA.

- Task 5: Uneven Settlement of the Invert. The fifth task will evaluate the potential for uneven settlement of the invert and the effect of such settlement on EBS response to seismic events. This task responds to an AIN from the NRC (Key Technical Issue Agreement Total System Performance Assessment and Integration 2.02, Comment J-2, Additional Information Need (AIN), (Kokajko 2005 [177025] [MOL.20050427.0113, pp. 5 to 6 of enclosure])).

- Task 6: Update of Cladding Damage Abstraction and Fault Displacement Damage Abstraction. The current damage abstraction for cladding is based on PWR fuel assemblies inside a 21-PWR waste package. This abstraction needs to be updated for PWR fuel assemblies inside the TAD-bearing waste package. The damage abstraction for fault displacement also needs to be updated because the inventory of different waste package types in the repository is changing and because waste packages may be placed in the contingency zone where another fault may be located.

- Task 7: Seismic Damage Abstractions. The results from the first five tasks provide the basis for the seismic damage abstractions for the waste package and drip shield in TSPA. The abstractions will be developed using standard statistical approaches and will propagate the appropriate uncertainties in the seismic damage models into TSPA. These abstractions are applicable over all relevant postclosure time periods, from closure to 1,000,000 years. Although the magnitude of seismic consequences will depend on antecedent conditions (such as rubble accumulation and drift collapse), which vary with time, the abstractions are applicable regardless of time. A DTN will be prepared during the revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) to formalize the transfer of the seismic damage abstractions to TSPA. This revision will also provide better traceability for DTNs: MO0303SPARBPDS.000 and MO0303SPARESST.000, as required to resolve CR 5110.

The technical product from the seven tasks covered by this TWP is a revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The methodology and results from Tasks

1, 2, 3, 4, and 5 will be documented in appendices to *Seismic Consequence Abstraction*; Tasks 6 and 7 will be documented in main body of this report. Table 2-1 provides additional information on this technical product.

1.3 ORGANIZATION AND SCHEDULE

The Disruptive Events organization, which reports to the Postclosure Activities organization, will perform the work described in this TWP. The structural engineering group at LLNL will provide assistance with finite-element calculations for the Disruptive Events organization. The Itasca Consulting Group will provide assistance with the structural response of a waste package or drip shield surrounded by rubble and with the dynamic response of the invert. The Disruptive Events organization will develop the damage abstractions for TSPA. The schedule is in a P3 database, which is maintained by the Project Controls department.

1.4 PRETEST PREDICTIONS

This section is not applicable, as testing is not within the scope of this TWP.

1.5 DESCRIPTION OF SCOPING ACTIVITIES

Scoping calculations are needed to assist in the development of the technical approaches for the kinematic calculations, for a waste package surrounded by rubble, and for drip shield failure mechanisms. These scoping calculations are being performed with qualified software on the appropriate computational platforms, as required by IT-PRO-0011, *Software Management*. The input and output files for the calculations are controlled and archived to meet all documentation requirements for LP-SIII.10Q-BSC. The results from the scoping calculations may be used to develop damage abstractions if input parameters, initial conditions, and boundary conditions for the scoping calculations versus final production calculations are unchanged or have minor changes that can be shown to be unimportant for the computational results. If the scoping results are carried forward into the damage abstractions, documentation will be included in the revision to *Seismic Consequence Abstraction* to support the qualification status of the scoping calculations.

2. SCIENTIFIC APPROACH OR TECHNICAL METHODS

2.1 WORK ACTIVITIES

2.1.1 Intended Use and Purpose of Activities and Products

Seven tasks will be performed under this TWP. The first five tasks are planned to support new damage abstractions for the TAD-bearing waste package and will be documented as appendices to the revised *Seismic Consequence Abstraction* model report. The development and validation of abstractions under Tasks 6 and 7 will be documented in the main body of this report. The purposes of the seven tasks are as follows:

1. Kinematic Calculations—The kinematic calculations define the probability of rupture and the damaged areas when the TAD-bearing waste package is free to move beneath an intact drip shield. The resulting damaged areas and probabilities of rupture in

response to vibratory ground motion provide the basis for developing seismic waste package damage abstractions.

2. Waste Package Surrounded By Rubble—These coupled rockfall/structural response calculations define the probability of rupture and the damaged areas when the waste package is surrounded by rubble, after failure of the drip shield plates. The resulting damaged areas and probabilities of rupture provide the basis for developing seismic waste package damage abstractions.

3. Drip Shield Failure Mechanisms—These numerical calculations define the plastic load capacity of the drip shield plates and drip shield framework as a function of static rockfall load and drip shield thickness. This information is used to define the fragility of the drip shield plates and drip shield framework as a function of rockfall load, plate thickness, and peak ground velocity (PGV). The rockfall load will be determined by rockfall calculations and represented as an abstraction for rubble accumulation during multiple seismic events. The resulting fragility curves for the drip shield and the abstraction for rubble accumulation are part of the new seismic damage abstractions for TSPA.

   Additional kinematic calculations within this task define the frequency and intensity of impacts between the waste package and interior bulkheads of the drip shield. These calculations are similar to the kinematic calculations for task 1, but focus on the potential for impacts of the waste package with the interior bulkheads of the drip shield. The result of these calculations is an assessment of the importance of waste package -drip shield impacts for the seismic scenario class. Detailed finite-element calculations for the structural response of the drip shield will be performed as a licensing support activity, if necessary.

4. Drip Shield Damaged Area—Structural response calculations define the damaged areas on the drip shield in response to vibratory ground motion and in response to rockfall induced by vibratory ground motion. This task will be performed only if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in for TSPA. The resulting damaged areas provide the basis for developing seismic drip shield damage abstractions for TSPA.

5. Uneven Settlement of the Invert—Evaluate the potential for uneven settlement of the invert and its effect on the orientation of emplaced drip shields, their rockfall load carrying capacity, and potential interactions with a waste package. The result of this study will be an assessment of the importance of uneven settlement of the invert for the seismic scenario class.

6. Update of Cladding Damage Abstraction and Fault Displacement Damage Abstraction—Revise the cladding damage abstraction to reflect the packaging of PWR and BWR waste forms in the TAD-bearing waste package. Revise the damage abstraction from fault displacement to represent the inventory of TAD-bearing waste packages in the repository and to represent the potential for emplacement of waste packages in the contingency zone of the repository.

7. Document the seismic damage models, based on the results from tasks (1) through (5), and prepare and document the seismic damage abstractions. The new damageabstractions will be documented in a revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The results for Tasks 1, 2, 3, 4, and 5 will be documented in appendices in the revised *Seismic Consequence Abstraction*.

The technical product from the activities covered by this TWP is a revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) to document the damage models and associated seismic damage abstractions. As part of this revision, an output DTN will be prepared to document the computational algorithm associated with the seismic damage abstractions for TSPA. The revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) will also provide better traceability for DTNs: MO0303SPARBPDS.000 and MO0303SPARESST.000, as required to resolve CR 5110.The new revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) will be referenced in the Safety Analysis Report. This product is scheduled for completion by the end of February 2007 and will be developed in accordance with LP-SIII.10Q-BSC.

The main users/customers of the seismic consequence abstraction and its output DTN are the TSPA organization (and the TSPA model), and the Criticality organization. The Repository Project Management-Subsurface-Subsurface Engineering-Thermal/Structural Analysis group is also a user of this product, in the sense that previous versions of *Seismic Consequence Abstraction* defined two DTNs related to the sizes and kinetic energies of large rock blocks and the residual stress threshold for Alloy 22. This information was used for calculations performed by the Thermal/Structural Analysis group. The revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) will provide better traceability for these two DTNs (MO0303SPARBPDS.000 and MO0303SPARESST.000), and will also include information required to satisfy the acceptance criteria in the *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274]), as described in Section 3.2.

Table 2-1 presents the intended purposes of the products covered by this TWP, and summarizes model validation activities and criteria. The damage models and associated abstractions for waste package damage (see tasks (1) and (2) and (7)) are new models that will be validated for Level III importance criteria. The abstractions for drip shield fragility, rubble accumulation around the drip shields, and drip shield damage models (see tasks (3) and (4) and (7)) are new models that will be validated for Level II importance criteria. If the updated cladding damage abstraction (see task (6)) is represented as a fragility curve, rather than a conservative bounding representation, then it is a model that will be validated for Level I importance criteria.

2.1.2 Scientific Approach and Technical Methods

The scientific approach and technical methods are described in Sections 2.2 and 2.3.

No field work packages are related or required by the activities covered by this TWP. Therefore, field work packages are not applicable to this TWP.

2.1.3 Methods for Data Collection

Testing is not in the scope of this TWP; therefore, this section is not applicable.

2.1.4 Provisions for Handling Unexpected Test Results

Testing is not in the scope of this TWP; therefore, this section is not applicable.

Table 2-1. Major Product: Intended Uses and Purposes

Product Title	Document Identifier	Intended Use and Purpose	Level of Confidence	Validation Activities	Model Validation Review Criteria
Seismic Consequence Abstraction	MDL-WIS-PA-000003 REV 03	Purpose of work described in this TWP is to develop damage abstractions for TSPA for seismic-induced damage to the TAD-bearing waste package, the drip shield, and the cladding. *Seismic Consequence Abstraction* documents the seismic-induced damage abstractions for the waste package, drip shield and cladding. The report also documents all the damage analyses that support the new damage abstractions.	III for the new waste package damage analyses and damage abstractions; II for the drip shield fragility curves, for rubble accumulation around the shields, and for drip shield damaged areas and damage abstractions I for a cladding damage fragility model if it is developed under this TWP.	The kinematic damage model will be validated by (1) corroboration of the technical approach with analog studies and other relevant observations, (2) comparison of kinematic calculations with LS-DYNA and an alternate computational technique, such as UDEC or 3DEC, and (3) a technical review by a reviewer for postdevelopment model validation. The purpose of the corroboration step is to demonstrate the reasonableness and representativeness of using the finite-element method for calculations of impact and vibration. The purpose of the second step is to build confidence by comparing kinematic results with an alternate representation for multiple waste packages in an emplacement drift. The first and second steps together provide validation of the kinematic model to criterion 5.3.2.a.1 in LP-SIII.10Q-BSC, while the third step provides validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC. The abstraction for kinematic damage to the waste package will be validated by (1) corroboration of the abstraction results with computational data from the damage model, and by (2) a technical review by a reviewer for postdevelopment model validation. These steps provide validation to criteria 5.3.2.a.2 and 5.3.2.a.5 of LP-SIII.10Q-BSC. The damage model for a waste package surrounded by rubble will be validated by (1) corroboration of the damage model with data from field experiment, and (2) a technical review by a reviewer for postdevelopment model validation. The first step demonstrates the reasonableness and representativeness of the computational approach for failure of a lined tunnel at the Nevada Test Site during a simulated nuclear event. The first step provides validation of the damage analyses to criterion 5.3.2.a.1 in LP-SIII.10Q-BSC, while the second step provides validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC. The abstraction for damage to a waste package surrounded by rubble will be validated by (1) corroboration of the abstraction results with computational data from the damage model, and by (2) a technical review by a reviewer for postdevelopment model validation. These activities provide validation to criteria 5.3.2.a.1 and 5.3.2.2.5 in LP-SIII.10Q-BSC. The abstraction for fragility of the drip shield and/or its plates and the	Note: The model validation criteria used previously in MDL-WIS-PA-000003 REV 01 and REV02 are still applicable: • Is the model abstraction reasonable and appropriate for its intended use? • For given inputs, are the outputs of the model abstraction reasonable? • Are limitations of the model abstraction adequately described?

Table 2-1. Major Product: Intended Uses and Purposes (Continued)

Product Title	Document Identifier	Intended Use and Purpose	Level of Confidence	Validation Activities	Model Validation Review Criteria
				abstraction for rubble accumulation will be validated by a technical review by a reviewer for postdevelopment model validation. These activities provide validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC The damage model for the drip shield (if needed) will be validated by a technical review by a reviewer for postdevelopment model validation, providing validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC. The abstraction for damaged area on the drip shield in response to vibratory ground motion and rockfall induced by vibratory ground motion will be validated by a technical review by a reviewer for postdevelopment model validation. This abstraction will only be developed and validated if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in for TSPA, as discussed in Section 2.1.5. The existing damage abstraction for cladding (MDL-WIS-PA-000003 REV 02) is being modified under this TWP. If the new damage abstraction for cladding is a conservative, bounding representation of cladding failure, then it is not a model and does not require validation. If a cladding fragility curve is developed under this TWP, then it will be validated by a technical review by a reviewer for postdevelopment model validation, per criterion 5.3.2.a.5 in LP-SIII.10Q-BSC. The existing damage abstraction for fault displacement (MDL-WIS-PA-000003 REV 02) will be modified to account for the change in waste package types in the inventory and the presence of waste packages in the contingency zone, but the technical approach and underlying framework of the abstraction are unchanged. The damage abstraction for fault displacement is considered a scientific analysis because it is based on a simple analysis that bounds component response through an analysis of clearances between waste package types and the underside of the drip shield. This abstraction does not require validation because it is not considered a model.	

2.1.5 List of Features, Events, and Processes

Table 2-2 provides a list of features, events, and processes (FEPs) to be addressed in this TWP. The screening decision for FEP 1.2.03.02.0C, Seismic Induced Drift Collapse Damages EBS Components, is being changed from exclude to include because the potential damage to the drip shield plates and drip shield framework from rockfall and ground motion is being explicitly included in the seismic scenario class through drip shield fragility curves. The screening decision for FEP 1.2.03.02.0B, Seismic Induced Rockfall Damages EBS Components, will be changed from exclude to include if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in for TSPA and the associated drip shield damage abstractions are developed for TSPA. The potential change in status for FEP 2.1.03.10.0B will depend on technical studies that are performed under *Technical Work Plan for: Near-Field Environment: Engineered Barrier System: Radionuclide Transport Abstraction Model Report,* TWP-MGR-PA-000020, REV 02 (in process). The results of these technical studies will be summarized in revisions to the Disruptive Events FEP report (BSC 2004 [DIRS 171850]) and the EBS FEP report (BSC 2005 [DIRS 175014]).

Table 2-2. Features, Events, and Processes Addressed in Seismic Product

FEP Number	FEP Name	Description	Reports/Calculations	Screening Decision
1.2.02.03.0A	Fault displacement damages EBS components	A fault intersects drifts within the repository. The fault undergoes movement. The EBS components experience related movement or displacement such that performance is degraded by such things as tilting of components, component-to component contact, or drip shield separation. Or, it could be as significant as failure due to the shearing of drip shields and waste packages by virtue of the relative offset across the fault, or as extreme as exhumation to the surface.	MDL-WIS-PA-000003, Seismic Consequence Abstraction	Damage to the drip shield, waste package, and cladding from fault displacement is: Included (DE)[a] Included (EBS)[a]
1.2.03.02.0A	Seismic ground motion damages EBS components	Seismic activity causes repeated vibration of the EBS components (drip shield, waste package, pallet, and invert). This could result in severe disruption of the drip shields and waste packages through vibration damage or contact between EBS components. Such damage mechanisms could lead to degraded performance.	MDL-WIS-PA-000003, Seismic Consequence Abstraction,	Damage to the waste package and cladding from vibratory ground motion is: Included (DE) Included (EBS) Damage to the drip shield from vibratory ground motion is evaluated but not abstracted for TSPA.

Table 2-2. Features, Events, and Processes Addressed in Seismic Product (Continued)

FEP Number	FEP Name	Description	Reports/Calculations	Screening Decision
1.2.03.02.0B	Seismic induced rockfall damages EBS components	Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced rockfall that could impact drip shields, waste packages, or other EBS components.	MDL-WIS-PA-000003, Seismic Consequence, Abstraction	Damage to the drip shield from seismic-induced rockfall is: Excluded – low consequence (DE) Excluded – low consequence (EBS); Will be changed to included if FEP 2.1.03.10.0B is screened in for TSPA
1.2.03.02.0C	Seismic induced drift collapse damages EBS components	Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse that could impact drip shields, waste packages, or other EBS components. Possible effects include both dynamic and static loading.	MDL-WIS-PA-000003, Seismic Consequence Abstraction	Damage to the drip shield and waste package from drift collapse is: Included (DE) Included (EBS)
1.2.03.02.0D	Seismic induced drift collapse alters in-drift thermohydrology	Seismic activity could produce jointed-rock motion and/or changes in rock stress leading to enhanced drift collapse and/or rubble infill throughout part or all of the drifts. Drift collapse could impact flow pathways within the EBS, mechanisms for water contact with EBS components, and thermal properties within the EBS.	MDL-WIS-PA-000003, Seismic Consequence Abstraction	Changes in host rock thermo-hydrology after drift collapse are: Included (DE) Included (EBS)

NOTE: [a]DE = Disruptive Events FEPs (BSC 2004 [DIRS 171850]), EBS = EBS FEPs (BSC 2005 [DIRS 175014]).

2.2 DAMAGE MODELS

The purpose of the damage models is to develop a revised set of waste package and drip shield damaged areas resulting from vibratory ground motion and from rockfall induced by vibratory ground motion for the TAD-bearing waste package. Additionally, the results from the damage models will be used to address an NRC issue raised in *Integrated Issue Resolution Strategy Report* (NRC 2002 [DIRS 159538]). Development of seismic damage abstractions from the revised data is described in Section 2.3.

The planned activities for numerical calculations of waste package or drip shield damage resulting from vibratory ground motion or from rockfall induced by vibratory ground motion are summarized below:

- Kinematic Calculations—Three-dimensional numerical kinematic calculations of waste packages, pallets, and drip shields subjected to postclosure ground motions[2], and detailed numerical calculations for the damage from individual impacts. The detailed damage calculations for individual impacts will include several outer barrier thicknesses and the potential for the waste package internals to be intact or degraded.

- Waste Package Surrounded by Rubble—Two-dimensional numerical calculations for the response a waste package surrounded by rubble in the lithophysal zone. The presence of rubble around the waste package is a function of the fragility of the drip shield and a function of the accumulation of rubble from multiple seismic events. Several outer barrier thicknesses and the potential for waste package internals to be intact or degraded represent the long-term degradation of the waste package and its internals.

- Drip Shield Failure Mechanisms—Three-dimensional numerical calculations of the plastic load capacity of the drip shield plates and drip shield framework, and kinematic calculations for the interaction of the waste package and drip shield in collapsed emplacement drifts. Detailed finite-element calculations for the damage/failure from impacts between the waste package and drip shield may be performed as a follow-on licensing support activity, if necessary.

- Drip Shield Damaged Areas—Finite-element numerical calculations for the damaged areas on the drip shield from vibratory ground motion and from rockfall induced by vibratory ground motion. Several plate thicknesses are considered to incorporate long-term degradation of the drip shield.

- Uneven Settlement of the Invert—A study of the potential for uneven settlement of the invert and its effect on the orientation of emplaced drip shields, their rockfall load carrying capacity, and potential interactions with a waste package.

The computational effort will be completed by the LLNL structural mechanics group and by the Itasca Consulting Group.

2.2.1 Kinematic Analyses

Three-dimensional kinematic calculations will examine the motion and impact of multiple waste packages, pallets, and drip shields in an emplacement drift. The objective of these analyses is to define the history of impact parameters for collisions of the waste packages, pallets, and drip shields as a function of the applied ground motion time histories, and to determine the associated probability of rupture and damaged areas on the waste package. A separate kinematic calculation is performed for each ground motion time history at four PGV levels. The kinematic calculations are appropriate to define the damage to the waste package when the drip shield is intact and the waste package can move freely beneath the drip shield.

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[2] The postclosure ground motions consist of a set of 17 ground motion time histories at each of three hazard levels (i.e., annual exceedance probabilities) 1×10^{-5} (PGV Level of 1.05 m/sec), 4.5×10^{-7} (PGV Level of 2.44 m/sec), and 1×10^{-8} (PGV Level of 4.07 m/sec) (BSC 2005 [DIRS 173247], Section 6.4). An additional set of 17 ground motions may be defined at 1×10^{-4} per year (PGV Level of 0.4019 m/sec) or at 5×10^{-4} per year (PGV Level of 0.2054 m/sec) by scaling down the ground motions for a PGV level of 1.05 m/sec.

The kinematic calculations consider a "string" of multiple waste packages in a section of an emplacement drift. The "string" will be composed of a combination of TAD-bearing waste packages and possibly some Defense High-Level Waste (DHLW) Long waste packages. The appropriate mix of waste packages and the number of waste packages will be chosen to make the number of waste packages representative of the package inventory and to make the response of the string representative of the middle of an emplacement drift, independent of the end conditions. That is, the string must have enough waste packages to make the response of the central waste packages independent of the free boundaries at either end of the string. As the design of the TAD canister and its overpack is not currently available, the site-specific canister design and the Naval Long waste package design will be used as a surrogate.

For computational efficiency, the kinematic calculations use relatively coarse finite-element representations of the waste package and pallet as elastic bodies that preserve the mass and dimensions of the components. The kinematic calculations are too coarse to directly determine the structural deformation or damage from multiple impacts. Instead, the damage induced by these impacts is calculated from the kinematic impact parameters for end-to-end impacts and for waste package-pallet impacts by using look-up tables. A direct correlation is made between damaged surface area and impact velocity, angle of impact, force of impact, and/or impact location, allowing the kinematic calculations to represent the damage to multiple waste packages without the penalty of running very detailed finite-element models. The final damaged area from multiple impacts is determined by summing the damaged areas from individual impacts, based on the look-up table and the impact parameters. These final damaged areas form the basis of the seismic damage abstractions for TSPA.

The kinematic calculations represent an emplacement drift that has partially or completely collapsed, with the result that the drip shield is pinned in place, and moves synchronously with the free field. *Drift Degradation Analysis* (BSC 2004 [DIRS 166107]) showed that complete collapse of the emplacement drifts in the lithophysal rock occurs at a PGV of approximately 2 m/sec, and that substantial rock blocks are dislodged at this level in the nonlithophysal unit as well. Even relatively small amounts of rockfall tend to pin the drip shield in place and prevent separation, as demonstrated in *Mechanical Assessment of the Drip Shield Subject to Vibratory Motion and Dynamic and Static Rock Loading* (BSC 2004 [DIRS 169753]). Therefore, the drip shield is represented as an upper boundary that moves synchronously with the free field for the kinematic calculations.

The input data for the kinematic calculations include the following:

- 17 ground motion time histories for the 1.05 m/sec, 2.44 m/sec, and 4.07 m/sec PGV levels. It is anticipated that a fourth PGV level, at 0.2 m/sec or 0.4 m/sec, will be required to define the response of the waste package over the full range of postclosure ground motions that can cause damage to degraded waste packages. The 17 ground motions at this fourth level will be generated by scaling the ground motions at the 1.05 m/sec PGV level. The same kinematic model is used at all PGV levels, and is valid and appropriate when extended to lower magnitude ground motions at the 0.2 m/sec or 0.4 m/sec PGV level.
- Friction coefficient for metal-to-metal (waste package-to-pallet and waste package-to-waste package) contacts

- Friction coefficient for metal-to-crushed tuff (invert) contact
- Elastic material properties of the waste package and pallet.

The uncertainty in the ground motions and in the friction coefficients is propagated into the kinematic calculations through sampled values for these input parameters. For each PGV level, GoldSim (BSC 2005 [DIRS 174650]) provides a Latin Hypercube sampling of the metal-to-metal friction coefficient, the metal-to-invert friction coefficient, and the ground motion number. Each friction coefficient is independently sampled from a uniform distribution with range of 0.2 to 0.8. The ground motion number is sampled from a discrete distribution from 1 to 17, with equal probability for each number. This sampling provides a list of input data in which a given time history (numbered from 1 to 17) is randomly paired with metal-to-metal and metal-to-invert friction coefficients for each waste package and pallet. This listing provides part of the will be used as a basis for input data for the kinematic calculations at the 1.05 m/sec, 2.44 m/sec, and 4.07 m/sec PGV levels, plus a fourth PGV level at 0.4 m/sec or 0.2 m/sec.

Uncertainty in the coefficient of restitution is not represented in the kinematic calculations because energy dissipation during contact is accounted for through contact damping, which is calibrated to produce conservative values of the coefficient of restitution (BSC 2005 [DIRS 173172], Sections V-2.2 and 3.2.16).

The kinematic calculations are designed to represent the rigid body motions of multiple waste packages, not the structural deformation of each waste package. Each waste package is therefore represented as an elastic body with the Young's modulus and Poisson's ratio defined at room temperature. While elastic properties vary with temperature, the use of room temperature values is a reasonable approximation for the rigid body interactions of the waste packages.

The output data from the kinematic calculations are a set impact parameters, including:

- Impact location and time of impact
- Relative velocity of the impacting bodies
- Relative angle of impact of the impacting bodies
- Force between the impacting bodies.

For every impact between adjacent waste packages or between a waste package and an emplacement pallet, the time, location, relative velocity, relative angle, and force of the collision will be recorded. The corresponding damage from multiple impacts during a given ground motion will be determined from a series of "look-up" tables that relate the relevant impact parameter(s) to surface area that has overcome a residual tensile stress criterion. The look-up tables for end-to-end impacts are generated from detailed finite-element calculations for the horizontal impact of a moving waste package onto an initially stationary (but not fixed) waste package. The look-up tables for waste package-pallet impacts are generated from detailed finite-element analyses of side-on impacts of a waste package on an emplacement pallet. The potential for rupture will also be determined from the look-up tables, based on the ultimate tensile strain of Alloy 22 and a "knockdown" factor that accounts for the potential effects of a biaxial stress field on the ultimate strength of a material. This "knockdown" factor provides an initial basis for screening cases with the potential for rupture. Once a case exceeds the knockdown factor, the detailed stress state is considered to determine if rupture occurs. The basis for the knockdown factor will be documented in the revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]).

The input data for the look-up table calculations include the temperature for material properties and the residual stress threshold for initiation of stress corrosion cracking in deformed areas. Elastic and plastic material properties will be set to constant values at 60°C from handbooks or manufacturer's catalogs. This temperature provides conservative values for material properties over the long time scales for the seismic scenario class. For example, the temperature of a hot 21-PWR waste package in a filled or unfilled drift is approximately 60°C at 10,000 years and 40°C at 20,000 years (BSC 2005 [DIRS 173944] Figure 6.3-57(a)). Similar results apply to the temperature of an average 44-BWR waste package and a cool DHLW waste package (BSC 2005 [DIRS 173944], Figures 6.3-55(a) and 6.3-56(a)). Material properties based on 60°C are then conservative over 99% of the 1,000,000-year period for TSPA.

A temperature of 60°C is not conservative for TSPA calculations lasting 10,000 years because the waste package temperature is above 60°C during most of the first 10,000 years after repository closure (BSC 2005 [DIRS 173944], Figures 6.3-55 through 6.3-57). A sensitivity study will assess the impact of the temperature for waste package material properties on damaged areas for 10,000-year calculations.

For planning purposes, the residual stress threshold for initiation of stress corrosion cracking on the Alloy 22 outer barrier is defined as a range from 90% to 110% of the yield strength of Alloy 22. Technical studies for *Technical Work Plan for Postclosure Waste Package Modeling and Testing* (BSC 2006 [DIRS 177033], Section 2.3.1.1) may refine this range. The uncertainty associated with this range will be propagated into TSPA by preparing separate look-up tables and abstracting damaged area at the extreme values of the range. The TSPA model will interpolate between these extremes to capture the uncertainty in the residual stress threshold.

Multiple look-up tables will be defined to represent a range of future states of the TAD-bearing waste package. For end-to-end impacts of adjacent waste packages, the future states are: 23-mm-thick outer barrier with intact internals, 23-mm-thick outer barrier with degraded internals, 17-mm-thick outer barrier with degraded internals, and 11-mm-thick outer barrier with degraded internals. These thicknesses are the average thickness of the outer barrier because average thickness is anticipated to be the key parameter for structural response. The first state, 23 mm with intact internals, represents the initial response for a waste package with intact internals. The outer barrier thickness for the first state has been reduced by 2.4-mm, from its 25.4-mm initial value to 23 mm, to represent the potential for general corrosion to reduce the thickness of the outer barrier before the first significant seismic event. After the first seismic event that damages the outer barrier, three future states with degraded internals represent the response of the waste package over very long time scales. These three states have outer barrier thicknesses of 23 mm, 17 mm, and 11 mm. The damage tables do not take credit for the stainless steel inner vessel and TAD canister as structural elements after the first seismic event that damages the outer barrier. This is a conservative representation because the stainless steel elements may not degrade quickly in a dilute chemical environment.

Each end-to-end look-up table has multiple entries for impact velocity, impact angle, and impact location. Impact location refers to the point of impact, such as edge-to-edge or edge-to-lid. For planning purposes, there are expected to be about five impact velocities (1 m/sec, 2 m/sec, 4 m/sec, 6 m/sec, and 10 m/sec), a relative impact angle of 1.5 degrees, and three impact locations for each look-up table, or about 15 calculations per table. Since there are four tables, the total number of calculations is estimated at around 60. Each set of calculations will produce two look-up tables: one for the top end and one for the bottom end of the TAD-bearing waste package because preliminary calculations indicate significant differences between the damage on the top versus the bottom end.

The relative impact angle of 1.5 degrees is an approximate mean value based on scoping kinematic calculations. The use of a mean value is appropriate because previous calculations indicate only a modest dependence of damage on impact angle once the angle is greater than zero degrees. Additional calculations at impact angles above and below 1.5 degrees, say at 0.5 degrees and 6 degrees, may be required to investigate the angular dependence of damage within the range of angles from the kinematic calculations. Additional calculations for impact velocities below 1 m/sec may also be required to define the impact velocity at which damage goes to zero.

The look-up tables for waste package-pallet impacts are structured in a similar manner to those for end-to-end impacts. The future states are 23-mm-thick outer barrier with intact internals, 23-mm-thick outer barrier with degraded internals, and 17-mm-thick outer barrier with degraded internals. A future state with an outer barrier thickness of 11 mm is not included here because the pallet has degraded to the point that it cannot support the weight of the waste package and is easily crushed. For planning purposes, each waste package-pallet look-up table has about five impact velocities (1 m/sec, 2 m/sec, 4 m/sec, 6 m/sec, and 10 m/sec) at two impact angles, and multiple impact locations between the waste package and pallet. The specific impact angles will be selected during the calculations for the look-up tables, based on the sensitivity of damaged areas to impact angle. Additional calculations below 1 m/sec may be required to define the impact velocity at which damage goes to zero.

These damage calculations will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The output from the damage calculations provides the basis for new seismic damage abstractions. Separate abstractions will be developed for the different outer barrier thicknesses, the state of the internals (intact or degraded), and the extremes of the residual stress failure criterion. The abstractions will be documented in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]), as described in Section 2.3.

These calculations will be performed with qualified versions of the finite-element software LS-DYNA currently under Software Configuration Management and listed on the Software Baseline Report. Specific versions of LS-DYNA are listed in Table 9-1.

The summation of damaged areas from individual impacts will be performed as a postprocessing step. The postprocessing software will be written in FORTRAN77 and/or FORTRAN90 and executed on the GPS DEC Alpha cluster at LLNL. The input for this software will be the kinematic impact parameters, the end-to-end damage look-up tables, and the WP-pallet damage look-up tables generated by LS-DYNA. The output from this software will be the damaged areas on the waste package and the potential for rupture of the waste package. This software, called *km_impacts_pp,* will be qualified in accordance with IT-PRO-0011, *Software Management,* under the activities performed for this TWP.

2.2.2 Calculations of Waste Package Surrounded by Rubble

The kinematic calculations in Section 2.2.1 are appropriate when the drip shield is intact and the waste package can move freely beneath the drip shield. But at late times, when the degraded drip shield plates may fail from rockfall and seismic loads, the waste package will be surrounded by rubble. The direct loads from this rubble may cause damage to the waste package in response to vibratory ground motion. Rubble in the lithophysal zone is most relevant here because the small particle size of the lithophysal rubble can more easily slip or fall through gaps or tears in the plates of the drip shield and because the lithophysal zones encompass approximately 85% of the emplacement drifts in the repository.

The damage induced by the rubble surrounding the waste package is based on the two-dimensional coupled rockfall/structural response of the Alloy 22 outer barrier during vibratory ground motion. Damage is determined directly from the finite-element output for the stress and strain state of the outer barrier; additional look-up tables are not required. The input data for the calculations of a single waste package surrounded by rubble include 17 ground motion time histories at each of 3 or 4 PGV levels, elastic and plastic properties of the outer barrier, and the elastic and plastic properties of the waste package internals (both intact and degraded). The rock block pattern in the lithophysal rock is based on a new random seed for each realization.

Several thicknesses of the outer barrier will be analyzed: 23-mm-thick, 17-mm-thick outer barrier, and 14-mm-thick outer barrier, all with degraded internals. These three states represent the response of the waste package over very long time scales. These thicknesses are the average thickness of the outer barrier because average thickness is anticipated to be the key parameter for structural response. The damage model does not take credit for the stainless steel inner vessel and TAD canister as structural elements after the first seismic event that damages the outer barrier. This is a conservative representation because the stainless steel elements may not degrade quickly in a dilute chemical environment. A case with intact internals is not included here because the internals will become degraded after the first seismic event that damages the outer barrier, and this event is anticipated to occur before failure of the drip shield plates allows rubble to come into contact with the waste package.

The numerical calculations for the 23-mm-thick outer barriers are anticipated to show minimal deformation from a circular cross-section, so a two-dimensional model provides a reasonable approximation for the deformation of the midsection of the waste package. The calculations for the 17-mm- and 14-mm-thick outer barriers are anticipated to show severe deformation from a circular cross-section, so that the three-dimensional effects of the ends and lids of the waste package must be considered. Fully coupled three-dimensional rockfall/structural response calculations are not computationally efficient for the long durations of the ground motions. In this situation, a decoupled approach will be applied for the calculations. In this decoupled approach, the external rockfall forces from the 17-mm-thick outer barrier calculations will be approximated and transferred to a three-dimensional structural calculation for the waste package. This approach directly includes the three-dimensional effects from the lids on the final structural deformation and provides a computationally efficient methodology for smaller values of the outer barrier thickness. The three-dimensional structural calculations may result in an alternate failure mechanism for the severely deformed package, such as failure of the end lids.

The uncertainty in the ground motions and in the rock block pattern is propagated into these calculations through sampled values for these input parameters. GoldSim (BSC 2005 [DIRS 174650]) provides a Latin Hypercube sampling of the rock block pattern and the ground motion number. The rock block pattern is defined by a random seed, here an integer, selected from a discrete distribution between 1 and 17, with equal probability for each integer. The ground motion number is sampled from a discrete distribution from 1 to 17, with equal probability for each integer. This sampling provides a list of input data in which a given time history is randomly paired with a random seed for the rock block pattern. This listing will be used as a basis for input data for the calculations at the 1.05 m/sec, 2.44 m/sec, and 4.07 m/sec PGV levels, plus a fourth PGV level at 0.4 m/sec or 0.2 m/sec.

Elastic and plastic material properties will be set to constant values at 60°C from handbooks or manufacturer's catalogs. This temperature is conservative for all EBS components after 10,000 years, resulting in conservative values for material properties over 99% of the time scale for the seismic scenario class (BSC 2005 [DIRS 173944], Figures 6.3-55(a) through 6.3-57(a)). A temperature of 60°C is not conservative for TSPA calculations for 10,000 years because the waste package temperature is above 60°C during most of the first 10,000 years after repository closure (BSC 2005 [DIRS 173944], Figure 6.3-57). A sensitivity study will assess the impact of the temperature for waste package material properties on the damaged areas during the first 10,000 years after repository closure.

For planning purposes, the residual stress threshold for initiation of stress corrosion cracking in the Alloy 22 outer barrier is defined as a range from 90% to 110% of the yield strength of Alloy 22. Technical studies for *Technical Work Plan for Waste Package Modeling and Testing* (BSC 2006 [DIRS 177033], Section 2.3.1.1) may redefine this range. The uncertainty represented by this range will be propagated into TSPA by preparing separate look-up tables and abstracting damaged area at the extreme values of the residual stress threshold. The damaged areas for the two extremes provide separate damage abstractions that can be interpolated to propagate this uncertainty in TSPA.

These damage calculations will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The output from the damage calculations provides the basis for new seismic damage abstractions. Separate abstractions will be developed for the different outer barrier thicknesses and the extremes of the residual stress failure criterion (if a range of values is defined for this parameter). The abstractions will be documented in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]), as described in Section 2.3.

These calculations will be performed by the distinct element program UDEC Version 3.1 (BSC 2002 [DIRS 161949]). It may be necessary to recompile and install UDEC on a PC cluster at Sandia National Laboratories if machine time is not available on BSC's PC cluster. In this event, UDEC will be requalified on the Sandia PC cluster in accordance with IT-PRO-0011, *Software Management,* under the activities performed for this TWP.

2.2.3 Drip Shield Failure Mechanisms

The drip shield will degrade and may fail mechanically in several ways over very long time scales:

- Its plates may rupture from the accumulated (static) rockfall load combined with the dynamic load induced by vertical seismic accelerations
- Its framework may buckle or collapse from the accumulated (static) rockfall load combined with the dynamic load induced by vertical seismic accelerations
- Its plates may be ruptured if the lip of a waste package impacts an interior bulkhead, tearing the plate where it is welded to the interior bulkhead

These mechanical failures are important within TSPA because they eliminate the drip shield as a barrier to seepage and advective flow. Drip shield failure causes advective flow through the drip shield and changes the waste package damage abstractions from those for the kinematic representation to those for a waste package surrounded by rubble or another appropriate configuration in TSPA.

The drip shield may also be deformed (but not experience mechanical failure) in response to vibratory ground motion and to rockfall induced by vibratory ground motion in the nonlithophysal zones. Drip shield deformation and the associated damaged areas are discussed in Section 2.2.4.

2.2.3.1 Drip Shield Plate and Drip Shield Framework Failures

The mechanical failure mechanisms for the drip shield plates and drip shield framework will be represented as a set of fragility curves that are functions of drip shield thickness, seismic intensity, and the static rockfall load on the drip shield. Within this context, mechanical failure refers to rupture of the drip shield plates or collapse/buckling of the drip shield framework. The fragility curves will be based on detailed two-dimensional and three-dimensional numerical calculations of the plastic load capacity of the drip shield plates and drip shield framework. The potential for rupture from waste package-drip shield impact on an interior bulkhead will be based on kinematic calculations for the interaction of the waste package and drip shield in collapsed emplacement drifts. Detailed finite-element calculations for the damage/failure from impacts between the waste package and drip shield may be performed as a follow-on licensing support activity, if necessary.

A series of two- or three-dimensional finite-element calculations will examine the load bearing capacity of the drip shield plates and/or drip shield framework when plastically loaded to the point of ultimate tensile failure (i.e., rupture). The plastic load bearing capacity of the plate or framework will be compared to the average static load from lithophysal rockfall combined with the vertical acceleration from vibratory ground motion. If the combined static load from rockfall plus dynamic load from ground motion is greater than the load-bearing capacity, then the structure has failed. Since the peak vertical load varies among the 17 ground motions at each PGV level, the results are represented as a probability of failure that is a function of plate thickness and static load at each PGV level. The curves for probability of mechanical failure define the fragility curves for the drip shield plates or drip shield framework.

The input data for the finite-element calculations include the elastic and plastic properties of the drip shield plates and/or drip shield framework, the design configuration of the drip shield, and the boundary conditions on the ends of the plates. Rubble in the lithophysal zone is most relevant here because the lithophysal zones encompass approximately 85% of the emplacement drifts in the repository. The plates and framework will be uniformly loaded because the typical size of the drip shield plates, approximately 1-meter on a side, or the drip shield itself, is significantly larger than the size of rubble particles in the lithophysal zones. Average joint spacing in the lithophysal zones is less than 1 meter, and at certain locations this spacing is much smaller, on the order of 0.1 meters (BSC 2004 [DIRS 166107], Section 6.1.4.1). The drifts in the lithophysal zone are predicted to collapse into small fragments with particle sizes of centimeters to decimeters (BSC 2004 [DIRS 166107], Section 8.1) under the loads imposed by vibratory ground motions.

Elastic and plastic material properties for the drip shield will be set to constant values at 60ºC from handbooks or manufacturer's catalogs. This temperature is conservative for all EBS components after 10,000 years, resulting in conservative values for material properties during 99% of the time scale for the seismic scenario class (BSC 2005 [DIRS 173944], Figures 6.3-55 through 6.3-57).

These calculations will be performed with qualified versions of the finite-difference program FLAC3D Version 2.1 (BSC 2002 [DIRS 161947]) or with the finite-element software LS-DYNA currently under Software Configuration Management and listed on the Software Baseline Report. Specific versions of LS-DYNA are listed in Table 9-1.

The static rockfall load will increase as rubble accumulates on the crown of the drip shield from multiple seismic events. A series of two-dimensional distinct-element calculations will examine rubble accumulation in the lithophysal zones as a function of lithophysal rock strength and the PGV level of the ground motions. Calculations for the 1.05 m/sec PGV level and 2.44 m/sec PGV level have already been reported in *Drift Degradation Analysis* (BSC 2004 [DIRS 166107]) for all five rock categories in the lithophysal zones. However, additional calculations are needed at the 0.4 m/sec or 0.2 m/sec PGV level to complete development of an abstraction for rubble accumulation.

The uncertainty in the ground motions and in the rock strength is propagated into the rockfall calculations through sampled values for these input parameters. GoldSim (BSC 2005 [DIRS 174650]) provides a Latin Hypercube sampling of the rock strength and the ground motion number. The rock strength is represented by five rock categories, numbered 1 through 5, representing the range of porosity and unconfined compressive strength observed in lithophysal rock. The rock category is sampled from a discrete distribution between 1 and 5 and the ground motion number is sampled from a discrete distribution from 1 to 17, with equal probability for each integer. This sampling provides a list of input data in which a given time history is randomly paired with a rock category.

The rubble abstraction will incorporate the uncertainty due to rock strength by basing the abstraction on the results for rock categories 2 through 5. These categories encompass approximately 95% of the lithophysal rock in the repository. This approach propagates the uncertainty in rock strength into the TSPA model.

The rockfall calculations will be performed by the distinct-element program UDEC Version 3.1 (BSC 2002 [DIRS 161949]).

The drip shield failure calculations and rockfall calculations will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The output from the damage calculations provides the basis for new fragility curves that will be documented in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]), as described in Section 2.3.

2.2.3.2 Potential for Plate Failures from Waste Package/Drip Shield Impacts

This task is an expansion of the kinematic studies for the waste package in Section 2.2.1. It will characterize the interactions between the waste package and drip shield in response to postclosure ground motions for an emplacement drift that has partially or completely collapsed and "pinned" the drip shield in place. The primary area of concern is the potential tearing of welds and associated rupture of the drip shield as a result of a waste package longitudinally impacting an internal bulkhead (rib) of the drip shield.

The potential damage to the waste package as a result of impacts with the drip shield have previously been shown (BSC 2005 [DIRS 173247], Section 6.5.3.1) to be an order of magnitude lower than damage due to a waste package having an end-to-end impact with an adjacent waste package. Although the waste package does not experience significant damage from impacts with the drip shield, there is the potential for mechanical failure when the edge or lip of a waste package longitudinally impacts or "clips" an internal rib on the underside of the drip shield. The potential for mechanical failure will be assessed through the three-dimensional kinematic calculations. These calculations will characterize the frequency and impact velocity between the TAD-bearing waste packages and the sides and internal ribs of the drip shield.

The result of this analysis will support an assessment of the importance of waste package-drip shield impacts for the seismic scenario class. A previous assessment was performed for the potential for drip shield failure from waste package impacts (BSC 2005 [DIRS 173172], Attachment VI). The previous assessment found that (i) each of the drip shield components remained within their true ultimate strengths through all but one of the impact scenarios, and (ii) a bulkhead could fail at the point of impact if it is clipped by a waste package, although this is a low probability event (BSC 2005 [DIRS 173172] Section VI-3.7). The frequency, impact velocity, and impact configuration between TAD-bearing waste packages and the sides and internal ribs of the drip shield will be compared to the results from the previous assessment to determine the potential for drip shield failure with the three-dimensional kinematics. This comparison will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]).

If this comparison indicates that drip shields or bulkheads may fail, a detailed numerical representation of a portion of the drip shield, surrounding rock rubble, and emplacement drift surface will be developed. This activity is envisioned as a Licensing Support activity, and will not be completed for the next revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). This detailed representation will address the stability of the drip shield when surrounded by rock rubble and subjected to seismic loading from the rock rubble and waste package impacts. The rock rubble representation within the finite-element model will require some development activity. It is currently assumed that a continuum finite-element representation will be employed in which the contact between the drip shield surfaces and the rubble is defined by an interface with shear and normal force transmission. Initially, the rubble mechanical behavior would be represented by an elastic material whose bulk modulus is derived in *Drift Degradation Analysis* (BSC 2004 [DIRS 166107], Section 6.4.2.5). An elastic representation for the rubble is likely to be reasonable and conservative since the rubble will be confined and any deformation will cause its compaction and hardening. Additionally, calculations will be performed to examine the sensitivity of the drip shield damage assessment to mesh discretization and drip shield geometry changes as a result of long-term thermo-mechanical creep and gravity loading from rock rubble. The calculations of the stability of the drip shield will include an assessment of potential failure mechanisms, such as weld tearing and buckling or collapse of the drip shield.

2.2.4 Drip Shield Damaged Areas

The drip shield can also be deformed by vibratory ground motion or by rockfall induced by vibratory ground motion, resulting in stress corrosion cracking in damaged areas with high residual stress. The damaged areas on the drip shield from vibratory ground motion and from rockfall induced by vibratory ground motion will be abstracted for TSPA if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in. The potential change in status for FEP 2.1.03.10.0B will depend on technical studies that are performed under *Technical Work Plan for: Near-Field Environment: Engineered Barrier System: Radionuclide Transport Abstraction Model Report,* TWP-MGR-PA-000020 REV 02 (in process). The results of these technical studies will be summarized in revisions to the Disruptive Events FEP report (BSC 2004 [DIRS 171850]) and the EBS FEP report (BSC 2005 [DIRS 175014]). The calculation of drip shield damaged areas considers both an open drift, where there can be relative movement between adjacent drip shields and where large rock blocks in the nonlithophysal zones can fall onto a drip shield, or a collapsed drift with rubble surrounding the drip shield.

Calculations for the response of a degraded drip shield to vibratory ground motion and to rockfall induced by vibratory ground motion have been performed with a 2-mm reduction in the thickness of the drip shield components (BSC 2004 [DIRS 169753], Sections 5.3 and 5.4). For planning purposes, this TWP assumes that these calculations, which provided a basis for previous drip shield damage abstractions, will be extended to more degraded conditions to represent the response of the drip shield over very long time scales.

These damage calculations will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]). The output from the damage calculations provides the basis for new seismic damage abstractions that will be documented in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]), as described in Section 2.3.

2.2.4.1 Drip Shield Damaged Areas from Vibratory Ground Motion

Three-dimensional finite-element calculations will examine deformation of several adjacent drip shields in an emplacement drift. The objective of these calculations is to define the deformation of the drip shield as a function of the applied ground motion time histories, and to determine the associated damaged areas on the drip shield. Several different thicknesses must be considered to represent degraded states of the drip shield. A separate calculation is performed for each ground motion time history at each of four PGV levels.

The input data for the drip shield calculations include the following:

- 17 ground motion time histories for the 1.05 m/sec, 2.44 m/sec, and 4.07 m/sec PGV levels. A fourth PGV level, at 0.2 m/sec or 0.4 m/sec, will be required to define the response of the degraded drip shield over the full range of postclosure ground motions.
- Friction coefficient for metal-to-metal (drip shield-to-drip shield or drip shield-to-waste package)
- Friction coefficient for metal-to-crushed tuff invert
- Elastic and plastic material properties.

Several drip shield plate thicknesses will be analyzed: 13 mm, 10 mm, and 5 mm. These three states represent the degradation of the drip shield over very long time scales.

The uncertainty in the ground motions and in the friction coefficients is propagated into the drip shield calculations through sampled values for these input parameters. For each PGV level, GoldSim (BSC 2005 [DIRS 174650]) provides a Latin Hypercube sampling of the metal-to-metal friction coefficient, the metal-to-invert friction coefficient, and the ground motion number. Each friction coefficient is independently sampled from a uniform distribution with range of 0.2 to 0.8. The ground motion number is sampled from a discrete distribution from 1 to 17, with equal probability for each number. This sampling provides a list of input data in which a given time history (numbered from 1 to 17) is randomly paired with metal-to-metal and metal-to-invert friction coefficients for each drip shield. This listing will be used as a basis for input data for calculations at the 1.05 m/sec, 2.44 m/sec, and 4.07 m/sec PGV levels, plus a fourth PGV level at 0.4 m/sec or 0.2 m/sec.

Elastic and plastic material properties will be set to constant values at 60°C from handbooks or manufacturer's catalogs. This temperature is conservative for all EBS components after 10,000 years, resulting in conservative values for material properties during 99% of the 1,000,000-year time scale for the seismic scenario class (BSC 2005 [DIRS 173944], Figures 6.3-55(a) through 6.3-57(a)). A temperature of 60°C is not conservative for TSPA calculations for 10,000 years because the waste package temperature is above 60°C during most of the first 10,000 years after repository closure (BSC 2005 [DIRS 173944], Figure 6.3-57). A sensitivity study will assess the impact of the temperature for drip shield material properties on the damaged areas during the first 10,000 years after repository closure.

For planning purposes, the residual stress threshold for initiation of stress corrosion cracking in the drip shield plates is defined as 50% of the yield strength of Titanium Grade 7. Technical studies for *Technical Work Plan for Waste Package Modeling and Testing* may redefine this value or may define a range of values to represent the uncertainty in this parameter (BSC 2006 [DIRS 177033], Section 2.3.1.1). If a range is defined, the uncertainty represented by this range will be propagated into TSPA by preparing separate look-up tables and abstracting damaged area at the extreme values of the residual stress threshold.

Damage is determined directly from the finite-element output for the stress and strain state of the drip shield plates, based on the residual stress threshold for initiation of stress corrosion cracking in Titanium Grade 7 or on the ultimate tensile strain for rupture of Titanium Grade 7.

These calculations will be performed with qualified versions of the finite-element software LS-DYNA currently under Software Configuration Management and list on the Software Baseline Report. Specific versions of LS-DYNA are listed in Table 9-1.

2.2.4.2 Drip Shield Damaged Areas from Rockfall in the Nonlithophysal Zones

Rockfall calculations in nonlithophysal rock have been reported in *Drift Degradation Analysis* (BSC 2004 [DIRS 166107], Section 6.3) for the 1.05 m/sec, 2.44 m/sec, and 5.35 m/sec PGV levels using a three-dimensional discontinuum model of the host rock. The results of these calculations provide a sequence of rock blocks, including their size and kinetic energy, which are dislodged from the drift walls and fall onto a simulated drip shield for each of 15 ground motions at the three PGV levels. The rockfall calculations do not directly determine the damage to the drip shield because the drip shield is represented as a simple rectangular boundary that defines the impact parameters for individual rock blocks. Rather, detailed three-dimensional finite-element calculations define the damaged areas or probability of rupture in a look-up table based on 6 or 7 block kinetic energies that span the range of block kinetic energy observed in the rockfall calculations (BSC 2004 [DIRS 169753], Section 5.4).

An additional set of nonlithophysal rockfall calculations at the 0.4 m/sec PGV level will be necessary to define the damaged area and probability of rupture when the drip shield has degraded to a 5-mm thickness. These rockfall calculations will be performed with the discrete-element software 3DEC (BSC 2002 [DIRS 161930]), which is qualified.

This approach directly parallels the approach in Section 2.2.1, wherein the kinematic calculations determine the frequency and intensity of multiple impacts during a ground motion, look-up tables provide the damaged areas or probability of rupture for the individual impacts, and total damaged area is calculated by summing the damaged areas from the individual impacts.

The current look-up table is based on a 2-mm reduction in the thickness of the drip shield components using material properties based on a temperature of 150°C. These calculations need to be repeated using elastic and plastic material properties set to constant values at 60°C from handbooks or manufacturer's catalogs. This latter temperature is conservative for all EBS components after 10,000 years, resulting in conservative values for material properties over 99% of the very long time scales for the seismic scenario class. The estimated number of calculations is approximately 21, assuming six or seven block kinetic energies and three stainless steel thicknesses: 13 mm, 9 mm, and 5 mm. These calculations will be performed with qualified versions of the finite-element program LS-DYNA currently under Software Configuration

Management and listed on the Software Baseline Report. Specific versions are listed in Table 9-1.

2.2.4.3 Drip Shield Damaged Areas from Rockfall in the Lithophysal Zones

Two potential sources of damage to the drip shield have previously been considered in the lithophysal zone: damage from the individual rock fragments that fall onto the drip shield and the static load on the drip shield from drift collapse (BSC 2005 [DIRS 173247], Section 6.6.2). The individual rock fragments are too small to do significant damage to the drip shield (BSC 2005 [DIRS 173247], Section 6.6.2.1) and the mean static loads from a collapsed drift are not predicted to collapse the drip shield (BSC 2005 [DIRS 173247], Section 6.6.2.2). Damage to the drip shield from rockfall in the lithophysal zone is not included in the drip shield damage abstraction for TSPA (BSC 2005 [DIRS 173247], Section 6.6.2).

This assessment is appropriate for a drip shield whose thickness has been reduced by 2 mm. However, more significant reductions in thickness will increase the structural deformation resulting from individual rock fragments and reduce the static load capacity of the drip shield. The finite-element calculations to examine the load bearing capacity of the drip shield plates when plastically loaded (Section 2.2.3.1) provide initial estimates of the damaged areas for a drip shield surrounded by rubble under vertical seismic accelerations. Alternately, calculations similar to those outlined in Section 2.2.2 for a waste package surrounded by rubble can be performed for a drip shield surrounded by rubble. These two potential approaches to calculating damaged areas will be evaluated to determine the optimal approach for determining drip shield damaged areas from lithophysal rockfall if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in.

2.2.5 Uneven Settlement of the Invert

A series of two-dimensional numerical calculations will evaluate the potential for uneven settlement of the invert and the effect of such settlement on the orientation of emplaced drip shields, their load carrying capacity, and their potential interactions with the waste packages. Uneven settlement can occur during vibratory ground motion because of corrosion of structural elements built into the invert. The input data for the invert settlement calculations include 17 ground motion time histories for each PGV level, and the mechanical properties, porosity, and grain size distribution of the crushed tuff in the invert.

The invert will be represented as an assembly of circular (two-dimensional) particles, which mechanically interact with each other. The macro properties (i.e., stiffness, friction angle and porosity) of the numerical representation of invert material will be the same as design properties of the crushed tuff in the invert. Sensitivity of the settlement predictions to the different realizations of particle geometry, which conform to the designed grain-size distribution, will be investigated. The effect of corrosion of steel structural elements inside the invert will be analyzed. Both the maximum and the most uneven settlements of the invert will be determined. In one case, which will result in the maximum settlement, porosity will be generated inside the crushed tuff at the locations of all structural elements that corroded away. In the other case, which will result in the most uneven settlement, porosity will be generated inside the crushed tuff at the locations of the structural elements on one side of the invert only, assuming uneven corrosion rates. In both cases, ground motions of different intensities will subsequently shake the invert. In these calculations carried out in the drift cross-section, the pallet, the waste package and the drip shield will be represented as relatively coarsely discretized objects with proper outside dimensions and mass. The drift outline will be represented by a number of straight segments that will act as a rigid wall moving synchronously with the prescribed free-field motion. The effect of rockfall, which will occur at the higher PGV levels and restrain deformation of the invert, will be neglected.

A similar approach will be used to assess variability of settlement along the drift. In this case, the two-dimensional calculations will be conducted in the vertical plane along the drift axis.

The change in orientation of the emplaced drip shields will be assessed from the computational results. This assessment will consider the potential changes to the load carrying capacity of the drip shields under static load of the rubble and under dynamic load by rock block impact. The assessment will also evaluate the potential changes in interactions between the drip shields and waste packages if uneven settlement occurs.

The settlement calculations will be performed by PFC2D (Particle Flow Code) Version 2.0 (BSC 2004 [DIRS 169930]) or PFC3D Version 2.0 (BSC 2004 [DIRS 169931]). These calculations will be documented in an appendix to *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]).

2.3 DAMAGE ABSTRACTIONS AND MODEL VALIDATION

The results from the damage calculations described in Section 2.2 provide the input data for the seismic damage abstractions. The damage abstractions will be designed to propagate the major uncertainties from the damage calculations into TSPA. These abstractions are applicable over all relevant postclosure time periods, from closure to 1,000,000 years. Although the magnitude of seismic consequences will depend on antecedent conditions (such as rubble accumulation and drift collapse), which vary with time, the abstractions are applicable regardless of time. The planned activities for developing new damage abstractions are as follows:

- New waste package damage abstractions will be developed for impacts between adjacent waste packages and for impacts between the waste package and pallet. Separate abstractions will be developed for the future states of the waste package: 23-mm-thick outer barrier with intact internals, 23-mm-thick outer barrier with degraded internals, 17-mm-thick outer barrier with degraded internals, and 11-mm-thick outer barrier with degraded internals. Each damage abstraction will define the probability of rupture, the probability of no damage, and the damaged area (conditional on damage occurring), all as functions of PGV. This approach is similar to the technical approach in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247], Section 6.5.1 through 6.5.3).

- New waste package damage abstractions will be developed for a waste package surrounded by lithophysal rubble. The presence of rubble around the waste package is a function of the accumulation of rubble on top of the drip shield from multiple seismic events and of the fragility of the drip shield plates (see next bulleted item). Separate abstractions will be developed for three future states of the system: 23-mm-thick outer barrier with degraded internals, 17-mm-thick outer barrier with degraded internals, and 14-mm-thick outer barrier with degraded internals. A state with intact internals is not considered here because the first seismic event that damages the outer barrier (and causes degradation of the waste package internals) is expected to occur before the drip shield plates fail.

- New drip shield damage abstractions will be developed for the fragility of drip shield plates and for the fragility of the drip shield framework, or both. These fragility curves will define the probability of mechanical failure of the drip shield plates or framework as a function of the static rockfall load, the vertical acceleration as a function of PGV level, and the thickness of the drip shield. The static load from rockfall will be a function of the accumulation of lithophysal rubble on top of the drip shield from multiple seismic events. The volume of lithophysal rubble will be defined through an abstraction that is a function of PGV level.

- New drip shield damaged area abstractions will be developed if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in.

- The cladding damage abstraction and the fault displacement damage abstraction will be updated to reflect the presence of the TAD-bearing waste package. The axial and lateral accelerations of fuel rod assemblies in the TAD-bearing waste package will be reanalyzed for the cladding damage abstraction. The clearances by waste package type will be reanalyzed to determine the potential for damage from displacement on known faults within the repository block, including faults within the contingency zone if necessary. The update to the cladding and fault displacement damage abstractions is discussed in the following section.

2.3.1 Update of Cladding and Fault Displacement Damage Abstractions

2.3.1.1 Cladding Damage Abstraction

The mechanical response of the waste package to vibratory ground motion can produce dynamic impacts between adjacent waste packages, between the waste package and its emplacement pallet, and between the waste package and the drip shield. During each of these impacts, the waste package may experience very high acceleration in the axial and lateral directions. These accelerations can be "transmitted" to the fuel rod assemblies and fuel rods contained in the TAD canister. The assemblies and fuel rods may impact the lid of the TAD canister due to axial impact of adjacent waste packages, or be pushed laterally during impact with the emplacement pallet. Either of these impacts has the potential to fail the fuel rod cladding (BSC 2005 [DIRS 173247], Section 6.5.6).

The fuel assembly axial accelerations from end-on impact of TAD-bearing waste packages and the lateral accelerations from side-on impact of the TAD-bearing waste package with the emplacement pallet will be determined by the postprocessing software (*km_impacts_pp*) for the kinematic calculations discussed in Section 2.2.1. Center of mass accelerations will be defined for the central waste package in the "string" of multiple waste packages for 17 ground motions at four PGV levels. The maximum lateral and axial accelerations for each ground motion will be compared to the g-loads for axial and lateral buckling discussed below.

The integrity of fuel rod cladding during impact has been extensively studied for zircalloy-clad light water reactor spent fuel assemblies. The work by Chun et al. (1987 [DIRS 144357]) explicitly calculates *g*-loads for axial buckling and for yielding due to side drops. The range of *g*-loads for failure due to axial buckling varies between 82 *g*'s for the Westinghouse 17×17 fuel assembly to 252 *g*'s for the Combustion Engineering 16×16 fuel assembly (Chun et al. 1987 [DIRS 144357], Table 4]). The range of *g*-loads for yielding due to side drops varies between 63 *g*'s for a Westinghouse 17×17 fuel assembly to 211 *g*'s for a Combustion Engineering 16×16 fuel assembly (Chun et al. 1987 [DIRS 144357], Table 4).

A comparison of the g-loads for axial buckling and for yielding due to side drops with the predicted axial and lateral accelerations from the kinematic calculations will define the probability of cladding failure as a function of the PGV level. Cladding failure may be represented as a conservative, bounding abstraction, or may be represented as a fragility curve (i.e., a probability of failure as a function of PGV level), depending on the nature of the results. The updated cladding damage abstraction will be documented in the revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) and in the output DTN from this report.

2.3.1.2 Fault Displacement Damage Abstraction

Seismic Consequence Abstraction (BSC 2005 [DIRS 173247], Section 6.7) defines the damage abstraction for the waste package, drip shield, and cladding in response to fault displacement. The abstraction for damage from fault displacement is based on the potential for the waste package and drip shield to be pinned when the displacement on a fault is greater than the available clearance between the waste package and drip shield for a collapsed drift. The use of TAD-bearing waste packages in place of 21-PWR and 44-BWR waste package reduces the available clearance between the waste package and drip shield for many waste packages in the inventory. Each TAD-bearing waste package also requires more linear space within an emplacement drift than a 21-PWR or 44-BWR waste package, making it more likely that waste packages will be emplaced in the contingency area of the repository. This is a significant change because a fault in the contingency area of the repository (the western splay off the main Ghost Dance Fault) was previously excluded from consideration in the damage abstraction for fault displacement.

Both of these changes will be incorporated into an update of the damage abstraction for fault displacement for TSPA. Note that the technical approach for defining damage from fault displacement is unchanged, and only input parameters are being altered. The damage abstraction for fault displacement is developed in Excel, which is exempt software. The damage abstraction from fault displacement will be documented in *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]).

2.3.2 Planned Document Revision Summary

Seismic Consequence Abstraction (BSC 2005 [DIRS 173247]) will be revised to document the new damage models and the new seismic damage abstractions as part of the work scope described in this TWP. An output DTN will be prepared during the development of the revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]) to formalize the transfer of the abstractions to TSPA.

2.3.3 Model Validation Activities

2.3.3.1 Model Validation Review Criteria for Adequacy and Accuracy

The model validation review criteria for adequacy of scientific basis and accuracy for intended use were previously provided in *Technical Work Plan for: Regulatory Integration Modeling of*

Drift Degradation, Waste Package and Drip Shield Vibratory Motion and Seismic Consequences (BSC 2004 [DIRS 171520]). These review criteria are as follows:

- Is the model abstraction reasonable and appropriate for its intended use?
- For given inputs, are the outputs of the model abstraction reasonable?
- Are limitations of the model abstraction adequately described?

These review criteria are still valid for the new damage models and the new damage abstractions documented in this TWP.

The existing damage abstraction for cladding (BSC 2005 [DIRS 173247]) is being updated under this TWP. The current cladding damage abstraction is considered a scientific analysis because it is a conservative, bounding approach. If the updated damage abstraction remains a conservative, bounding approach, then the updated abstraction is not considered a model so it does not require model validation. If the updated damage abstraction for cladding becomes a fragility curve (i.e., a probability of failure as a function of PGV), it is a model that will be validated with these three review criteria.

No validation is necessary for the abstraction of damage from fault displacement. The existing damage abstraction for fault displacement (BSC 2005 [DIRS 173247]) is being modified to account for the greater percentage of TAD-bearing waste packages in the inventory and the potential to emplace waste packages in the contingency area of the repository. However, the technical approach for the abstraction is unchanged. This technical approach is considered a scientific analysis because it bounds the component response through a simplified analysis of clearances between different waste package types and the drip shield. The damage abstraction for fault displacement is not considered a model, so it does not require validation.

2.3.3.2 Level of Confidence Required

The level of confidence required for validation of the damage models and damage abstractions for the waste package is high (Level III) because damage to the waste package is a significant factor in determining dose in TSPA calculations. LP-2.29Q-BSC, *Planning for Science Activities*, Table 1, requires two postdevelopment validation methods to meet a Level III validation.

The level of confidence required for damage abstractions, fragility curves, or damage calculations related to the drip shield, is moderate (Level II). An intact drip shield can deflect seepage and rockfall away from the waste package, thereby reducing advective releases from the waste package, but has no impact on the diffusive releases through stress corrosion cracks in the waste package. The drip shield therefore has a lesser role than the waste package as a barrier to radionuclide releases and is identified as Level II. A Level II model requires one postdevelopment validation method.

If cladding fragility curves are developed under this TWP, the level of confidence required for validation is low (Level I) because the cladding is not considered a significant barrier. Although intact cladding may delay the release of radionuclides, it does not play a major role as a barrier in

TSPA, so Level I is appropriate. A Level I model requires one postdevelopment validation method.

2.3.3.3 Model Validation Activities

The model validation activities for the waste package (Level III), the drip shield (Level II), and the cladding (Level I) are summarized in Table 2-1 and described in detail in this section.

The kinematic model for the waste package will be validated by: (1) corroboration of the computational method with studies for impact and vibration of large engineering structures, (2) comparison of kinematic results with LS-DYNA to an alternate computational technique, such as UDEC or 3DEC, and (3) a technical review by a reviewer for postdevelopment model validation. The purpose of the corroboration step is to demonstrate the reasonableness and representativeness of using the finite-element method for calculations of impact and vibration with large engineering structures. The purpose of the second step is to build confidence by comparing kinematic results from LS-DYNA with an alternate representation for multiple waste packages in an emplacement drift. The first and second steps together provide validation of the kinematic model to criterion 5.3.2.a.1 in LP-SIII.10Q-BSC, while the third step provides validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC.

The abstraction for kinematic damage to the waste package will be validated by (1) corroboration of the abstraction results with computational data from the damage model, and (2) a technical review by a reviewer for postdevelopment model validation. These steps provide validation to criteria 5.3.2.a.2 and 5.3.2.a.5 of LP-SIII.10Q-BSC.

The damage model for a waste package surrounded by rubble will be validated by (1) corroboration of the damage model with data from a field experiment, and (2) a technical review by a reviewer for postdevelopment model validation. The first step will compare UDEC results to the Mighty North field test for a steel lined tunnel in blocky rock under explosively induced ground motion. This test is a close analog to a waste package surrounded by lithophysal rubble and subjected to vibratory ground motion. The first step provides validation of the damage model to criterion 5.3.2.a.1 in LP-SIII.10Q-BSC, while the second step provides validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC.

The abstraction for damage to a waste package surrounded by rubble will be validated by (1) corroboration of the abstraction results with computational data from the damage model, and by (2) a technical review by a reviewer for postdevelopment model validation. These activities provide validation to criteria 5.3.2.a.2 and 5.3.2.a.5 in LP-SIII.10Q-BSC.

The required skills of the technical reviewer(s) for postdevelopment model validation are expertise in structural engineering, in structural response calculations, and in the application of probabilistic and statistical methods to natural hazards and their effects on structures. Specific qualifications and training requirements relative to the selection of the technical reviewer(s) for model validation are provided in Appendix A. The review criteria for the technical review are identified in Section 2.3.3.1. Documentation of the review(s) will be a brief report of the independent analysis. Training will include the curriculum appropriate for Scientific Support Technician Category and familiarity with the relevant sections of this TWP.

The abstraction for fragility of the drip shield and/or its plates and the abstraction for rubble accumulation will be validated by a technical review by a reviewer for postdevelopment model validation. These activities provide validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC

The damage model for the drip shield (if needed) will be validated by a technical review by a reviewer for postdevelopment model validation, providing validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC.

The abstraction for damaged area on the drip shield in response to vibratory ground motion and rockfall induced by vibratory ground motion will be validated by a technical review by a reviewer for postdevelopment model validation. This step provides validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC. This abstraction will only be developed and validated if FEP 2.1.03.10.0B, Advection Through Cracks in the Drip Shield, is screened in for TSPA, as discussed in Section 2.1.5.

The required skills of the reviewer(s) for postdevelopment model validation are expertise in structural engineering, in structural response calculations, and in the application of probabilistic and statistical methods to natural hazards and their effects on structures. Specific qualifications and training requirements relative to the selection of the technical reviewer(s) for model validation are provided in Appendix A. The review criteria for the technical review are identified in Section 2.3.3.1. Documentation of this review will be a brief report of the independent analysis. Training will include the curriculum appropriate for Scientific Support Technician Category and familiarity with the relevant sections of this TWP.

The level of confidence required for validation of the cladding fragility model, if developed under this TWP, is low (Level I). The cladding fragility model will be validated by a technical review by a reviewer for postdevelopment model validation, providing validation to criterion 5.3.2.a.5 in LP-SIII.10Q-BSC.

2.3.3.4 Schedule of Reviews for Model Validation Quality Issues

For this revision of *Seismic Consequence Abstraction*, the responsible manager will meet with the originator prior to the origination of the document, with the checker prior to the checking of the document, and with the independent technical reviewer(s) prior to the independent technical reviews. These meetings will cover model validation quality issues.

2.3.4 Justification for Use of Previously Developed and Validated Model for Scientific Analysis as per LP-SIII.9Q-BSC

The models for rockfall in the lithophysal and nonlithophysal zones will be used during the tasks for this TWP. These rockfall models were previously developed and validated, as documented in (BSC 2004 [DIRS 166107], Section 7). The application of the rockfall models for this TWP is within the intended use, limitations, and validity of these models. Rockfall calculations will be performed at the 0.4 m/sec PGV level for this TWP. This PGV level is much smaller than the PGV levels for previous rockfall calculations (1.05 m/sec, 2.44 m/sec, and 5.35 m/sec). In this situation, the new rockfall calculations will have less severe response of the rock mass than has been previously validated, so the rockfall models remain valid for this TWP.

2.3.5 Justification for Use of Previously Developed Model Outside Intended Use, Limitations or Range of Validity

New models are being developed and new model validation activities are planned to address the reasonableness of the outputs and the range of validity for the damage models. Previously developed models for rockfall in the lithophysal and nonlithophysal zones are not being used outside their intended use, limitations, or range of validity (see Section 2.3.4). This section is therefore not applicable to this TWP.

3. INDUSTRY STANDARDS, FEDERAL REGULATIONS, DOE ORDERS, REQUIREMENTS, AND ACCEPTANCE OR COMPLETION CRITERIA

3.1 INDUSTRY STANDARDS

The work will incorporate the guidance and data provided in the following documents:

- *2001 ASME Boiler and Pressure Vessel Code* (ASME 2001 [DIRS 158115])
- *Properties and Selection: Stainless Steels, Tool Materials and Special-Purpose Metals* (ASM 1980 [DIRS 104317])
- *Properties and Selection: Nonferrous Alloys and Special-Purpose Materials* (ASM International 1990 [DIRS 141615]).

3.2 FEDERAL REGULATIONS, DOE ORDERS, REQUIREMENTS, AND ACCEPTANCE OR COMPLETION CRITERIA

The applicable federal regulations and technical requirements related to the work activities associated with this TWP are generally implemented through the appropriate implementing procedures identified in Section 4. In particular, the requirements identified in 10 CFR 63.114 (a), (b), (c) and (g) are implemented through procedure LP-SIII.10Q-BSC. The requirements identified in 10 CFR 63.114 (d), (e) and (f) are implemented in the appropriate features, events and processes screening Analysis Reports which are discussed in the Disruptive Events FEP report (BSC 2004 [DIRS 171850]) and the EBS FEP report (BSC 2005 [DIRS 175014]). There are no additional specific requirements listed in the Requirements Management System related to the activities covered in the TWP. There are no DOE orders applicable to the scope of work identified in this TWP. The following requirements from 10 CFR 63 [DIRS 173273] are applicable to the scope of work described in this TWP:

Section 63.114 – Requirements for Performance Assessment

- 10 CFR 63.114 (a): Include data related to the geology, hydrology, and geochemistry (including disruptive processes and events) of the Yucca Mountain site, and the surrounding region to the extent necessary, and information on the design of the engineered barrier system used to define parameters and conceptual models used in the assessment.

- 10 CFR 63.114 (b): Account for uncertainties and variabilities in parameter values and provide for the technical basis for parameter ranges, probability distributions, or bounding values used in the performance assessment.

- 10 CFR 63.114 (c): Consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding and evaluate the effects that alternative conceptual models have on the performance of the geologic repository.

- 10 CFR 63.114 (d): Provide the technical basis for models used in the performance assessment such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).

- 10 CFR 63.114 (e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes in the performance assessment. Specific features, events, and processes must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.

- 10 CFR 63.114 (f) Provide the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting radiological exposures to the reasonably maximally exposed individual, or radionuclide releases to the accessible environment, would be significantly changed by their omission.

- 10 CFR 63.114 (g): Provide the technical basis for models used in the performance assessment such as comparisons made with outputs of detailed process-level models and/or empirical observations (e.g., laboratory testing, field investigations, and natural analogs).

The results from this development will also address portions of integrated subissue ENG2, Mechanical Disruption of Engineered Barriers, including the acceptance criteria for this subissue defined by *Yucca Mountain Review Plan, Final Report* (NRC 2003 [DIRS 163274], Section 2.2.1.3.2.3). Table 3-1 links the detailed acceptance criteria to specific outputs in the next revision of *Seismic Consequence Abstraction*. Technical products developed according to this TWP will be coordinated with Licensing to address the appropriate key technical issues and agreements with the NRC from the relevant technical exchanges.

Table 3-1. Mapping of the Technical Product to Yucca Mountain Review Plan Acceptance Criteria

YMRP Acceptance Criteria	Response in *Seismic Consequence Abstraction*
AC1: System Description and Model Integration are Adequate	
(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the mechanical disruption of engineered barrier abstraction process;	The damage models and associated damage abstractions for TSPA directly incorporate the important design features, seismic and mechanical response, and the potential for coupled rockfall-seismic effects for TSPA. Consistent assumptions are used to represent the response from closure to 1,000,000 years.
(2) The description of geological and engineering aspects of design features, physical phenomena, and couplings, that may affect mechanical disruption of engineered barriers, is adequate. For example, the description may include materials used in the construction of engineered barrier components, environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) on these materials, and mechanical-failure processes and concomitant failure criteria used to assess the performance capabilities of these materials. Conditions and assumptions in the abstraction of mechanical disruption of engineered barriers are readily identified and consistent with the body of data presented in the description;	Damage models for *Seismic Consequence Abstraction* consider material properties, the effect of temperature on the properties, the criterion for initiation of stress-corrosion cracking, the criterion for tensile failure, and other failure mechanisms. The results from the damage models are directly represented as abstractions for damaged area and rupture of individual components.
(3) The abstraction of mechanical disruption of engineered barriers uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for mechanical disruption of engineered barriers are consistent with the abstraction of degradation of engineered barriers (Section 2.2.1.3.1 of the Yucca Mountain Review Plan). The descriptions and technical bases provide transparent and traceable support for the abstraction of mechanical disruption of engineered barriers;	The seismic damage abstractions are consistent with DOE data for initiation of stress corrosion cracking, time dependent ground motions, corrosion of EBS components, and the design of EBS components.
(4) Boundary and initial conditions used in the total system performance assessment abstraction of mechanical disruption of engineered barriers are propagated throughout its abstraction approaches;	The ground motions, which are the primary boundary condition for the damage calculations, are propagated throughout the abstraction process. The temperature for material properties is the primary initial condition and is applied consistently to all damage calculations.
(5) Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided;	Table 2-2 in this document and a similar table in *Seismic Consequence Abstraction* report provide explicit guidance on the treatment of seismic-related FEPs.
(6) The conclusion, with respect to the impact of transient criticality on the integrity of the engineered barriers, is defensible;	Not applicable because criticality is beyond the scope of *Seismic Consequence Abstraction*.
(7) Guidance in NUREG–1297 and NUREG–1298 (Altman, et al., 1988a,b), or other acceptable approaches, is followed.	Not applicable because peer review and qualification of existing data are not used in the development of *Seismic Consequence Abstraction*.
AC2: Data Are Sufficient For Model Justification	
(1) Geological and engineering values, used in the license application to evaluate mechanical disruption of engineered barriers, are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided;	Geologic data and design data are justified elsewhere. The use of temperature-dependent material properties to derive mechanical properties at 60°C is explained in *Seismic Consequence Abstraction*.

Table 3-1. Mapping of the Technical Product to Yucca Mountain Review Plan Acceptance Criteria (Continued)

YMRP Acceptance Criteria	Response in Seismic Consequence Abstraction
(2) Sufficient data have been collected on the geology of the natural system, engineering materials, and initial manufacturing defects, to establish initial and boundary conditions for the total system performance assessment abstraction of mechanical disruption of engineered barriers;	Not applicable because collection of geologic data, engineering data, and data on initial manufacturing defects is beyond the scope of *Seismic Consequence Abstraction*.
(3) Data on geology of the natural system, engineering materials, and initial manufacturing defects, used in the total system performance assessment abstraction, are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment abstraction are adequate to determine the possible need for additional data;	Not applicable because collection and analysis of geologic data, engineering data, and data on initial manufacturing defects is beyond the scope of *Seismic Consequence Abstraction*.
(4) Engineered barrier mechanical failure models for disruption events are adequate. For example, these models may consider effects of prolonged exposure to the expected emplacement drift environment, material test results not specifically designed or performed for the Yucca Mountain site, and engineered barrier component fabrication flaws.	Damage models provide information on the initiation of stress corrosion cracking and on the potential for tensile failure of the engineered barriers in response to vibratory ground motion and fault displacement.
AC3: Data Uncertainty is Characterized and Propagated Through the Model Abstraction	
(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate;	*Seismic Consequence Abstraction* explains the basis for the parameter values, assumed ranges, probability distributions, and bounding assumptions that are relevant to the damage abstractions for the seismic scenario class.
(2) Process-level models used to represent mechanically disruptive events, within the emplacement drifts at the proposed Yucca Mountain repository, are adequate. Parameter values are adequately constrained by Yucca Mountain site data, such that the effects of mechanically disruptive events on engineered barrier integrity are not underestimated. Parameters within conceptual models for mechanically disruptive events are consistent with the range of characteristics observed at Yucca Mountain;	The seismic damage abstractions are not process-level models. Key inputs, such as the ground motion time histories, have been developed to capture the range of response expected at Yucca Mountain; however, development of ground motions is beyond the scope of *Seismic Consequence Abstraction*. On the other hand, the damage models are generally based on finite-element or discrete element representations that are standard engineering approaches to represent mechanical response to seismic events within the emplacement drifts.
(3) Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the assessment abstraction of mechanical disruption of engineered barriers. This may be done either through sensitivity analyses or use of conservative limits;	Uncertainty from the damage models is directly represented in the seismic damage abstractions. Alternate conceptual models are also considered in the seismic damage abstractions by evaluating different statistical distributions for the data. This information is presented in *Seismic Consequence Abstraction*.
(4) Where sufficient data do not exist, the definition of parameter values and conceptual models is based on	Not applicable because an expert elicitation has not been conducted for *Seismic Consequence Abstraction*.

Table 3-1. Mapping of the Technical Product to Yucca Mountain Review Plan Acceptance Criteria (Continued)

YMRP Acceptance Criteria	Response in *Seismic Consequence Abstraction*
appropriate use of expert elicitation, conducted in accordance with NUREG–1563 (Kotra, et al., 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.	
AC4: Model Uncertainty is Characterized and Propagated Through the Model Abstraction	
(1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction;	Alternate conceptual models and modeling approaches are considered in developing the seismic damage abstractions. For example, different statistical distributions are evaluated to represent the damaged area data. Alternately, two different computational approaches for the kinematic model were considered in the past. This information is presented in *Seismic Consequence Abstraction*.
(2) Consideration of conceptual model uncertainty is consistent with available site characterization data, laboratory experiments, field measurements, natural analog information and process-level modeling studies; and the treatment of conceptual model uncertainty does not result in an under-representation of the risk estimate;	Alternate conceptual models are considered in representing the uncertainty in the seismic damage abstractions. For example, different statistical distributions are evaluated to represent the uncertainty in the damaged area data. Similarly, two different computational approaches for the kinematic models were considered to represent model uncertainty. This information is presented in *Seismic Consequence Abstraction*.
(3) Appropriate alternative modeling approaches are investigated that are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations using tests and analyses that are sensitive to the processes modeled.	Alternate conceptual models and modeling approaches are considered in developing the seismic damage abstractions, as noted above.
AC5: Model Abstraction Output is Supported by Objective Comparisons	
(1) Models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs);	Quantile plots and other comparisons presented in *Seismic Consequence Abstraction* demonstrate that the damage abstractions accurately represent seismic-induced damage as a function of PGV, including the uncertainty at individual PGV levels.
(2) Outputs of mechanical disruption of engineered barrier abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both;	Quantile plots and other comparisons presented in *Seismic Consequence Abstraction* demonstrate that the damage abstractions accurately represent seismic-induced damage as a function of PGV, including the uncertainty at individual PGV levels.
(3) Well-documented procedures, that have been accepted by the scientific community to construct and test the mathematical and numerical models, are used to simulate mechanical disruption of engineered barriers;	The damage models are based on finite-element or discrete element representations that are standard engineering approaches to represent mechanical response to seismic events within the emplacement drifts. The damage abstractions are compared to the resulting damaged areas using standard statistical techniques, such as quantile plots and other comparisons. Finally, an independent technical review for model validation is performed for the major abstractions to ensure acceptance by the scientific and risk engineering community.
(4) Sensitivity analyses or bounding analyses are provided to support the total system performance assessment abstraction of mechanical disruption of engineered barriers that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.	The damage abstractions span the range of observed damage areas, so further sensitivity analyses or bounding analyses are not necessary.

3.3 OTHER ACCEPTANCE OR COMPLETION CRITERIA

The activities covered by this TWP will meet the level of detail and accuracy needed to support the TSPA model. In particular, the purpose of this work is to develop representative seismic-induced damage estimates and the uncertainty in those estimates, considering the design of EBS components and other site-specific information and design. The purpose is not to have a "precise" or "accurate" estimate, but a reasonable estimate that captures the uncertainty. Technical products that are not deliverables will be considered acceptable if they are developed, checked, reviewed (not applicable to calculations), and approved in accordance with the appropriate implementing procedures (Section 4).

This TWP, as well as the revision to *Seismic Consequence Abstraction* governed by this TWP, will be DOE deliverables per AP-7.5Q. Both of these documents will be subject to criteria as described in the associated deliverable definition sheets.

4. IMPLEMENTING DOCUMENTS

The following procedures or any superseding versions will be used to perform any modeling or computational work, as appropriate, to individual tasks within work packages. No additional implementing documents will be developed to control and perform any activity. If any non-Q work is to be performed requiring process controls, it will be performed using the process steps established in the procedures cited in this section.

- AP-SIII.3Q, *Submittal and Incorporation of Data to the Technical Data Management System*
- PA-PRO-0601, *Document Review*
- LP-2.29Q-BSC, *Planning for Science Activities*
- IT-PRO-0011, *Software Management*
- LP-SIII.2Q-BSC, *Qualification of Unqualified Data*
- LP-SIII.10Q-BSC, *Models*.

5. EQUIPMENT

Technical products from computational and modeling activities (analyses, models, reports, and calculations) will be prepared using ordinary office equipment, including project-standard desktop computers. Software will be run on project-standard workstations. No field or lab systems will be used; therefore, calibration requirements and methods for addressing instrument error are not applicable.

6. RECORDS

Records generated as a result of implementing procedures listed in Section 4 will be collected and submitted to the records processing center in accordance with AP-17.1Q, *Records Management*.

7. QUALITY VERIFICATIONS

Personnel working to this TWP will assist with routine audits, surveillance, and self-assessments as appropriate. No mandatory hold points or readiness reviews will be required during the execution of this TWP.

8. PREREQUISITES, SPECIAL CONTROLS, ENVIRONMENTAL CONDITIONS, PROCESSES, OR SKILLS

8.1 QARD REQUIREMENTS

Calculations and modeling activities performed under this TWP are subject to the requirements of *Quality Assurance Requirements and Description* (QARD) (DOE 2006 [DIRS 176927]) because they are associated with the characterization of the waste form and waste package in support of performance assessment.

8.2 NON-Q WORK

Any non-Q activities not specifically addressed in previous sections will be subject to the general requirements of *Augmented Quality Assurance Program* (DOE 2004 [DIRS 171341]) and will be planned and controlled through appropriate procedures listed in Section 4. Environmental compliance requirements for field activities are not discussed here because no field activities are planned in the TWP.

8.3 PREREQUISITES

The following prerequisites will be met prior to initiation of specific activities under this TWP:

- As stated in Section 2.3.3.4, the responsible manager will meet with the originator prior to the origination of the document, with the checker prior to the checking of the document, and with the independent technical reviewer(s) prior to the independent technical reviews. These meetings will cover model validation quality issues.

- Software that supports this TWP will be evaluated to ensure that the software is qualified and controlled on the software baseline. If the software is not on the baseline, qualification of required software will be initiated. In particular, the postprocessor for the kinematic calculations (see section 2.2.1) will be qualified during the activities performed for this TWP, and UDEC will be requalified if it is installed on the Sandia PC cluster, and LS-DYNA will be requalified when its current computational platform is retired from service at LLNL. All software will be qualified prior to the start of production calculations.

- The qualifications of the proposed technical reviewer(s) for model validation will be confirmed before the review activity is initiated.

The previously developed model for lithophysal rockfall will be used to support the rockfall calculations for accumulation of rubble on the drip shield.. This rockfall model is being exercised for its intended use and within its range of validity. If the rockfall model requires further validation, this TWP will be modified with a justification and plan for the new validation activities.

All data that support the damage models and the development of damage abstractions must be qualified. The major sources of these data include design drawings for the Site-Specific Canister and Naval Long waste package, engineering IEDs, and DTNs that contain qualified data. No need for data that are unqualified has been identified at this time. However, if unqualified data or data from external sources will be used, planning for the qualification of these data or for the justification of these data for their intended use will be performed per LP-SIII.2Q-BSC, Qualification of Unqualified Data, or LP-SIII.10Q-BSC, respectively.

Ongoing work on seismic ground motions is planned in the seismic studies TWP (TWP-MGR-GS-000001 REV00 in process). However, any revisions to the ground motion time histories will not be incorporated into the tasks performed for this TWP. These revisions are intended to confirm the conservatism in the damage calculations and damage abstractions developed under this TWP, and will not be direct input to the TWP.

Revised values for the residual stress thresholds of Alloy 22 and Titanium Grade 7 are currently under development by the Waste Package Modeling and Testing Department of the Postclosure Activities organization. Screening arguments for FEP 2.1.03.10.0B will also be developed by the Postclosure Activities organization, although these screening arguments do not result in direct input for seismic damage models. No other organizations are responsible for developing new input for the activities identified under this TWP.

8.4 CONTROL OF ELECTRONIC MANAGEMENT OF INFORMATION OR QARD SUPPLEMENT V REQUIREMENTS

An evaluation in accordance with IT-PRO-0009, *Control of the Electronic Management of Information* has been conducted, and this work is subject to requirements to manage and control electronic data. The results of this evaluation will be submitted to the Records Processing Center as part of the records package of this TWP.

The following controls will be instituted for the management of electronic data transfer, based on the technical work and IT-PRO-0009. Additional controls for electronic management of information are identified in the procedures cited in Section 4 of this TWP.

To ensure accuracy and completeness of the information generated by the activities identified in this TWP, access to information on the computer workstations used by all staff shall be controlled with password protection. Access privileges are set to prevent unauthorized changes to files housed on network servers. In addition, the servers are periodically backed up and the backups labeled and stored. All electronic files used in this activity are stored and backed up on network servers.

8.5 ENVIRONMENTAL CONTROL

No special environmental controls are required for activities covered by this TWP.

8.6 TRAINING

No special training or qualification, over and above training to the relevant procedures listed in Section 4, is required for activities covered by this TWP. Specific qualifications and training requirements relative to the selection of the independent reviewer(s) for model validation are provided in Appendix A.

9. SOFTWARE

Several versions of Microsoft Excel will be used to support the activities for this TWP. Microsoft Excel is commercial off-the-shelf software that is exempt software as defined by IT-PRO-0011, *Software Management*. These versions include Excel 97 SR-2 on a PC with the Microsoft Windows 2000 operating system, Excel 2000 on a PC with the Microsoft Windows 2000 Professional operating system, and Excel 2000 on a PC with the Microsoft Windows XP Professional operating system.

The nonexempt software used for this TWP is qualified, with the exception of the FORTRAN postprocessor discussed below. A list of those software codes that are currently qualified is presented in Table 9-1. The list of software in Table 9-1 may not be exhaustive; other qualified software versions may be used, as appropriate. However, all software will be managed and documented in accordance with IT-PRO-0011.

The list of software in Table 9-1 includes one legacy code: UDEC Version 3.1. UDEC Version 3.1 has been successfully retested through the process defined in IT-PRO-0014, *Independent Verification and Validation of Legacy Code*.

Table 9-1. Software Used

Software	Version	Software Tracking Numbers	Qualification Status
LS-DYNA*	970.3858 D MPP	10300-970.3858 D MPP-00	Qualified
LS-DYNA SMP D**	970.3858	10300-970.3858-01	Qualified
LS-DYNA SMP D***	970.3858	10300-970.3858-02	Qualified
GoldSim	8.02.500	10344-8.02-05	Qualified
UDEC	3.1	10173-3.1-00	Qualified
3DEC	2.01	10025-2.01-00	Qualified
FLAC3D	2.1.4	10502-2.14-00	Qualified
PFC2D	2.0	10828-2.0-01	Qualified
PFC3D	2.0	10830-2.0-01	Qualified

* BSC 2003 [DIRS 166918]; **BSC 2005 [DIRS 172926]; ***BSC 2005 [DIRS 172925]

A FORTRAN postprocessor will be written to define the damaged areas from the kinematic calculations discussed in Section 2.2.1. This software will be written in FORTRAN77 and/or FORTRAN90 and executed on the GPS DEC Alpha cluster at LLNL. This software, called *km_impacts_pp,* will be qualified in accordance with IT-PRO-0011, *Software Management,* under the activities performed for this TWP. In addition, UDEC and LS-DYNA will be requalified if the software is installed on new platforms. UDEC will be requalified if it is recompiled and installed on the Sandia PC cluster running the UNIX operating system. LS-DYNA will be requalified on a new platform at LLNL when its existing platform is retired from service. The anticipated retirement date for the existing platform is October 2006.

No continuous use software will be used by products of this TWP.

10. ORGANIZATIONAL INTERFACES

The work in this TWP will be performed by the Disruptive Events organization, which is a part of the Postclosure Activities organization.

Customer organizations include: (1) TSPA, which uses the output of the technical product in this TWP to evaluate the performance of the waste package, the drip shield, and the waste form as part of the TSPA, (2) the Criticality organization, which uses the output of the technical product in this TWP to evaluate criticality-related issues for the waste package, and (3) Licensing, which uses the technical product in this TWP to address key technical issues and Safety Analysis Report development. The Naval Nuclear Propulsion Program will be a reviewer for the technical product in the TWP to ensure consistency with their Technical Support Document for the License Application.

Organizations providing input include: (1) Design and Engineering, which provides input on waste package and drip shield design, and (2) the Postclosure Activities organization Engineered Systems group, which supplies general corrosion thinning information on the waste package Alloy 22 outer barrier, on the Alloy 22 and Stainless Steel Type 316 pallet components of the, and on the drip shield Titanium Grades 7 and 24 components.

11. PROCUREMENT

Procurement of items and services shall be in accordance with processes identified in procurement procedures governed by the BSC QA program as appropriate for the activity identified. BSC subcontracts are identified and processed using EG-PRO-3DP-G06B-00002, *Subcontracts*, and related procedures. BSC Technical Service Agreements are identified and processed using EG-PRO-3DP-G04B-00057, *Technical Service Contracts*, and related procedures.

12. REFERENCES

12.1 DOCUMENTS CITED

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173944 BSC 2005. *Multiscale Thermohydrologic Model.* ANL-EBS-MD-000049 REV 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050711.0001.

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APPENDIX A

PLANNING FOR TECHNICAL REVIEWS FOR THE PURPOSE OF MODEL VALIDATION

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PLANNING FOR TECHNICAL REVIEWS FOR THE PURPOSE OF MODEL VALIDATION

A.1 MODELS USING TECHNICAL REVIEW AS A VALIDATION METHOD

The Responsible Manager has elected to use an independent technical review as a method for postdevelopment validation of damage models and damage abstractions developed under this TWP. The damage models and damage abstractions, which are identified and discussed in Table 2-1, are as follows:

- Kinematic damage models for the waste package
- Abstraction for kinematic damage to the waste package
- Damage model for a waste package surrounded by rubble
- Damage abstraction for a waste package surrounded by rubble
- Fragility curves for failure of the drip shield plates/framework
- Damage models for the drip shield
- Damage abstractions for the drip shield
- Cladding fragility curves, if developed.

A.2 SELECTION OF TECHNICAL REVIEWER AND REVIEW CRITERIA

The damage models, damage abstractions, and fragility curves will utilize a technical review as a method of postdevelopment per LP-SIII.10Q-BSC, Section 5.3.2. The general requirements for the model validation technical reviewer are provided in Section 2.3.3.3.

A.3 SPECIFIC QUALIFICATION AND SELECTION CRITERIA FOR THE TECHNICAL REVIEWERS

The specific qualification and selection criteria for the technical reviewer postdevelopment model validation of the damage models are as follows:

- Ph.D. in structural engineering, mechanical engineering, civil engineering, or a related field

- Minimum of 15 years of research experience in computational analysis of structural response, as evidenced by publication record

- Minimum of 5 years of research experience in the application of probabilistic and statistical methods to natural hazards and their effects on structures, as evidenced by publication record.

The specific qualification and selection criteria for the technical reviewer for postdevelopment model validation of the damage abstractions and fragility curves are as follows:

- Ph.D. in structural engineering, mechanical engineering, civil engineering, statistics, or a related field

- Minimum of 5 years of research experience in computational analysis of structural response, as evidenced by project work, professional activities, and publications

- Minimum of 15 years of research experience in the application of probabilistic and statistical methods to natural hazards and their effects on structures, as evidenced by project work, professional activities, and publications.

A.4 SPECIFIC REVIEW CRITERIA

The specific model validation review criteria are summarized in Table 2-1 and discussed in Section 2.3.3.1.

A.5 REVIEW DOCUMENTATION

The basis for selection of the technical reviewer postdevelopment model validation and the results of the validation review will be documented in the revision of *Seismic Consequence Abstraction* (BSC 2005 [DIRS 173247]).

APPENDIX B

IT-PRO-0009 PROCESS CONTROL EVALUATION

BSC	**Process Control Evaluation for the Electronic Management of Information** *Complete only applicable items.*	QA: QA Page 1 of 1

A. Procedure/Work Activity Identification (check one)

☐ Procedure (identify process procedure number, title, revision and ICN level being evaluated), or

☒ Work Activity (identify by work package number, Technical Work Plan, technical product, etc., including title and revision)

TWP-MGR-GS-000004, Revision 01, *Technical Work Plan for: Analysis of Waste Package and Drip Shield Response to Vibratory Ground Motion and Revision of Seismic Consequence Abstraction*

B1. Processes/Process Function/Work Activities Evaluation

		Yes	No
1.	Will, or does, the process/process function/work activity depend on a form of electronic media to store, maintain, retrieve, modify, update, or transmit information?	☒	☐
2.	Will, or does, the process/process function/work activity manage, control, or use an electronic database, spreadsheet, set of files, or other holding system for information?	☒	☐
3.	Will, or does, the process/process function/work activity transfer information electronically from one location to another? (The method may be File Transfer Protocol, electronic download, tape to tape, disk to disk, etc.)	☒	☐
4.	Will, or does, the process/process function/work activity produce any Sensitive Unclassified electronic information?	☐	☒

If the answers to Section B1 are all "No", process in accordance with Step 4.1.2.7; otherwise proceed to Section B2.

B2. Processes/Process Functions/Work Activities Compliance Evaluation

		Yes	No	N/A
1.	If any Sensitive Unclassified electronic information is produced, are the process controls in accordance with AP-SEC-001?	☐	☐	☒
2.	Does the procedure or work activity document provide adequate controls to protect information from damage and destruction for its prescribed lifetime?	☒	☐	☐
3.	Does the procedure or work activity document provide adequate controls to ensure that information is readily retrievable?	☒	☐	☐
4.	Does the procedure or work activity document provide adequate controls to describe how information will be stored with respect to media, conditions, location, retention time, security, and access?	☒	☐	☐
5.	Does the procedure or work activity document provide adequate controls to properly identify storage and transfer media as to source, physical and logical format, and relevant date?	☒	☐	☐
6.	Does the procedure or work activity document provide adequate controls to ensure completeness and accuracy of the information input and any subsequent changes?	☒	☐	☐
7.	Does the procedure or work activity document provide adequate access to controls to maintain the security and integrity of the information?	☒	☐	☐
8.	Does the procedure or work activity document provide adequate controls to ensure that transfers are error free or within a defined permissible error rate? (e.g., copying raw information from notebook to electronic information form, electronic media to another electronic media, or File Transfer Protocols)	☒	☐	☐

If a "No" answer is given for any question in Section B2, proceed to Section C; otherwise process in accordance with Step 4.1.2.7. Mark "N/A" for those items that are not applicable to the specific process or work activity.

C. Results of Evaluation

Provide a summary of the "as-is condition," proposed remedial actions, and expected completion date of document revision, for each item in Section B2 that was indicated as "No."

Responsible Manager	Date
[signature]	5/16/06

IT-PRO-0009.3-r0

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